STATE OF NORTH DAKOTA

Red River of the North Research Investigation

A REPORT

Prepared by

THE NORTH DAKOTA STATE DEPARTMENT OF HEALTH

Covering the

JOINT INVESTIGATION

by

THE NORTH DAKOTA STATE DEPARTMENT OF HEALTH
THE MINNESOTA STATE BOARD OF HEALTH

in collaboration with

THE UNITED STATES PUBLIC HEALTH SERVICE

1938 — 1941

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NORTH DAKOTA STATE DEPARTMENT OF HEALTH

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[Bismarck, 1942]

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To the U. S. Geological Survey and Office of the State Engineer in furnishing hydrometric data, including stream flows and stream velocities.

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To Dean L. C. Harrington and the Board of Administration of the University of North Dakota for furnishing laboratory space, janitor service, lights, heat, water, etc.

To the municipalities, the officials of which aided in securing samples and records of waste discharges.


DRAINAGE BASIN
RED RIVER OF THE NORTH
LEGEND
SEWERAGE SYSTEM - NO TREATMENT
SEWERAGE SYSTEM - PARTIAL TREATMENT
SEWERAGE SYSTEM - COMPLETE TREATMENT
SAMPLING STATION-RED RIVER
SAMPLING STATION-TRIBUTARIES
BOUNDARY OF DRAINAGE BASINS
N
LAKE WINNIPEG
WINNIPEG
MANITOBA
NORTH DAKOTA
SOUTH DAKOTA
MINNESOTA
ROLETTE
TOWNER
CAVALIER
PEMBINA
KITTSON
ROSEAU
WALSH
MARSHALL
BELTRAMI
PIERCE
BENSON
NELSON
PENNINGTON
GRAND FORKS
RED LAKE
SHERIDAN
WELLS
EDDY
POLK
CLEAR-WATER
GRIGGS
STEELE
TRAILL
NORMAN
MAHNOMEN
CASS
CLAY
BECKER
BARNES
RANSOM
RICHLAND
WILKIN
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MARSHALL
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PREFACE

No extensive information dealing with the effect of ice coverage on the oxygen relationships in a stream was available prior to the undertaking of this study. Repeated requests for such information were received from various agencies concerned with the formulation of a comprehensive water plan for the Red River of the North drainage basin. Specific recommendations in regard to the minimum stream flows necessary for the maintenance of satisfactory standards of stream sanitation were requested.

Accordingly, the North Dakota State Department of Health sought the allocation of Social Security funds for conducting field and laboratory studies necessary to obtain this information. The State Health Officer, Maysil M. Williams, M.D., and the former Director of the Division of Sanitary Engineering, M. D. Hollis, requested and obtained the cooperation of the United States Public Health Service. As a result, Social Security funds were allocated to the State to conduct a research investigation for a period of eight months. Although the original allotment of funds expired by June 30, 1939, it was found necessary to continue the investigation until March 1940.

Mr. J. K. Hoskins, Senior Sanitary Engineer; H. R. Crohurst, Senior Sanitary Engineer; and Frank R. Shaw, Senior Sanitary Engineer, all of the U. S. Public Health Service, assisted in the organization and direction of the study. Mr. C. C. Ruchhoft, Principal Chemist, U. S. Public Health Service, made a field trip covering sampling stations on the Red River south of the International Boundary. He also visited the laboratories in Grand Forks and furnished consultation service on field and laboratory procedures during the course of the study.

The Minnesota Department of Health, A. J. Chesley, M.D., Executive Officer, upon request collected and examined all biological samples. They made special studies of the beet sugar plant wastes and sewage discharged from East Grand Forks, Minnesota. Also, all information on sewage and waste discharge and treatment in Minnesota was furnished. This work was carried out by the Division of Sanitation, Mr. H. A. Whittaker, Director. Mr. H. G. Rogers, Sanitary Engineer, was in responsible charge with Engineers James Drake and Lloyde Kempe obtaining the samples and field information. Theodore Olson, biologist, identified and enumerated the biological organisms.

The study was under the immediate direction of the North Dakota State Department of Health, Maysil M. Williams, M.D., State Health Officer; through the Division of Sanitary Engineering. Harry G. Hanson, Assistant Sanitary Engineer, was in charge of general supervision. Jerome H. Svore was field engineer in charge at Grand Forks, and Gilbert Groff, Chemical Engineer, was responsible for the

chemical laboratory work. K. C. Lauster, Assistant Sanitary Engineer, replaced Mr. Svore during his absence after September 1939. Bacteriological examinations were made under the direction of M. E. Koons, Director, Division of Laboratories.

During the course of the study, four meetings were held to review the progress of the work and to outline future activities. These meetings were attended by representatives of all participating agencies.

This report has been prepared by the Division of Sanitary Engineering of the North Dakota State Department of Health. Jerome H. Svore, Assistant Sanitary Engineer, has been responsible for compilation of data, preparation of graphs and tables, and mathematical and narrative detail. A tentative draft of the report was reviewed by all participating agencies; a comprehensive written review was prepared by a special board of engineers from the United States Public Health Service comprised of H. W. Streeter, Senior Sanitary Engineer; H. R. Crohurst, Senior Sanitary Engineer; C. C. Ruchhoft, Principal Chemist; and M. D. Hollis, Assistant Public Health Engineer.

It is hoped that this report provides the basic information essential to the satisfactory completion of the sanitary phases of a comprehensive water plan for the Red River of the North.

LLOYD K. CLARK, Director
Division of Sanitary Engineering
North Dakota State Department of Health

INTRODUCTION

Two studies have been made on the Red River previous to the present study. In 1931, 1932, and 1933 a joint investigation was made by the Minnesota State Board of Health and the North Dakota State Board of Health in collaboration with the Division of Game and Fish, Minnesota Department of Conservation. It was concluded from the results obtained during this investigation "that in order to improve the existing polluted conditions of the Red River and to promote the best interests of those concerned, it will be necessary to provide treatment for the sewage and industrial wastes from all of the municipalities from Breckenridge to Grand Forks and East Grand Forks inclusive, and for all of the major industrial wastes which are discharged separately into the section of the river under consideration."

In February 1938 a joint investigation was made by the North Dakota State Department of Health and the Minnesota State Board of Health. The "conclusions and requirements" of the report on this survey confirmed the findings of the previous investigation. In addition it was recommended that a more extensive research investigation of the river be made in order to determine the full effects of ice coverage on the oxygen relationships.

The present study was made by the North Dakota State Department of Health in conjunction with the Minnesota State Board of Health with the United States Public Health Service acting in an advisory capacity. The field and laboratory work was performed by personnel of the North Dakota State Department of Health. The biological data were collected and analyzed by the Minnesota Department of Health.

The purpose of this investigation was to obtain information which would serve:

1. To determine the oxygen relationships in the stream before and during ice coverage.
2. To determine the rate of oxygen depletion in the stream during ice coverage.
3. To determine the suitability of relatively unpolluted streams for dilution purposes.
4. To determine characteristics and quantities of the various wastes entering the river.

The above information makes possible the computation of minimum stream flows required for the maintenance of a satisfactory standard of stream sanitation. See Appendix IV.

During the course of the study considerable research data were obtained on low temperature B.O.D.'s of Flour Mill, Packing Plant, and Beet Sugar Plant wastes. Time and space do not allow for the interpretation and inclusion of these results in detail in this report.

SUMMARY AND CONCLUSIONS

Some addition to the conclusions reached as a result of previous studies may be made on the basis of information obtained in this study. General agreement with the conclusions reached as a result of previous studies was observed.

From the information collected during this and previous investigations, the following conclusions have been drawn:

1. Under ice coverage dissolved oxygen content of the River was depleted to zero in a few weeks except where aeration provided by dams exerted appreciable influence.

2. With flows of 200 c.f.s. very unsatisfactory conditions prevailed below Grand Forks during the winter critical period.

3. The quantity and nature of the wastes entering the river is such that without additional treatment, the amount of dilution water which reasonably could be provided would not solve the pollution problem.

4. High stream flows were accompanied by less septic conditions than were low flows. The less septic condition resulted not only from increased dilution but also from increased stream velocity.

5. During the winter critical period and summer critical period, flows from tributaries (except the Red Lake, Ottertail, Sheyenne, Buffalo, and the Minnesota Wild Rice Rivers) were insignificant from the standpoint of pollution contributed and dilution provided.

6. Overflow dams (less than 12 feet high) of the type in the Red and Red Lake Rivers, appear capable of providing sufficient aeration to increase the dissolved oxygen content of low temperature oxygen-deficient water to approximately 6 p.p.m. Since dissolved oxygen values during summer periods were not observed to be below about 6 p.p.m. at these dams, no information was collected on aeration by dams during summer months. Undoubtedly, the effectiveness of such dams as aerating devices could be improved if they were designed with this end in view.

7. It has been observed that, due to natural pollution* alone, the oxygen content of waters stored in reservoirs or river channels is likely to be diminished seriously or depleted entirely. Therefore, to be of greatest value for dilution purposes during the winter critical season, impounded waters should be aerated upon release from reservoirs.

8. Sludge deposits appear to exert an appreciable effect on the River. During periods of higher flow, organic material deposited at lower flows is dislodged and increases the pollution loading on the stream. However, at flows less than those required to dislodge sludge particles, the pollution load also may be increased. This latter effect is attributed to the direct solution of deposited organic

*Not receiving discharges of municipal or industrial wastes. The extent of rural pollution from barnyard drainage, dumped manure, and refuse such as has been observed is not known.

matter and of oxygen-requiring decomposition products of anaerobic sludge digestion. Entrainment of material floated by gas from digestion processes was observed.

9. Relatively unpolluted streams may, due to natural pollution alone, become completely devoid of dissolved oxygen during the ice coverage period.

10. Research information obtained in this study indicates that the rate and extent of oxygen utilization by industrial wastes depends upon several variable factors including nature of the waste, temperature, extent of dilution and the type of dilution water. It is essential to determine not only the basic behavior of each industrial waste separately but also to determine its effect in combination with other wastes under specific stream conditions. Since the behavior of an industrial waste may be quite different than that of domestic sewage, the fallacy of forecasting the effect of industrial wastes on the basis of the behavior of domestic sewage is evident.

PHYSICAL CHARACTERISTICS

The Red River of the North, located almost at the geographic center of the North American continent, is one of the few rivers that follows a course practically due north. Starting at Wahpeton, North Dakota and discharging into Lake Winnipeg in Manitoba, it forms most of the boundary between North Dakota and Minnesota. The river is formed by the confluence of the Ottertail and Bois-de-Sioux Rivers, the latter forming the remainder of the North-Dakota-Minnesota boundary and headwatering in Lake Traverse.

GEOLOGY

During the glacial period Lake Agassiz was formed covering the area which is now known as the Red River Valley. Originally this lake drained toward the south through Lake Traverse and Big Stone Lake, but when the ice receded lower outlets toward the north were opened from time to time, eventually lowering the elevation of the lake below the southern outlet of Lake Traverse. This receding occurred in stages. The shore line elevations were well marked and may be seen today in the form of a series of gravel ridges formed by the action of the waves. The tributaries of Lake Agassiz carried considerable silt, the heavier particles being deposited at the mouth forming a delta and the finer particles being carried out into the lake. With the receding of the lake these delta formations caused a partial damming effect at the mouth of the tributaries causing some to change their courses. The North Dakota Wild Rice River at one time joined the Red River near Wahpeton, but now enters a few miles south of Fargo. The deposition of the finer particles over the lake bottom formed the excellent agricultural land that is found in the valley today. The central portion of the drainage area, originally the lake bottom, has a flat topography. The entire drainage system

of the Red River gives the impression of a very old river. Geologically it is considered youthful, its winding course resulting from the cutting of the channel in the very level surface of the lake bottom.

TOPOGRAPHY

The river distance from Wahpeton to the International Boundary is 394 miles, or practically twice the airline distance between the two points. The slope, in general, is slight and diminishes toward the north. The surface altitudes above mean sea level are: 980 feet at Lake Traverse; 963 feet at Wahpeton; 900 feet at Fargo; 830 feet at Grand Forks; 789 feet at the International Boundary; and 755 feet at Winnipeg. The flat gradient of the river (approximately one-half foot drop per mile) produces a very sluggish condition, and considerable pooling occurs during periods of low flow. A heavy growth of aquatic vegetation flourishes during periods of low water in the summer as a result of the rich organic bottom and the shallow littoral margins. Transpiration and evaporation losses are large, and in some stretches of the river, notably between Wahpeton and Fargo, apparent losses have ranged from small percentages during high flows to nearly 100 per cent during very low flows.

The drainage area of the River above the International Boundary is 35,895 square miles. Of this, 670 square miles are in South Dakota, 16,065 square miles in North Dakota, 17,165 square miles in Minnesota, and 1995 square miles in Canada along the upper Pembina River.

Portions of the valley are flat marshy lands which seldom if ever contribute to the annual runoff of the basin. However, the above figures assume all lands to drain into some river or tributary.

TRIBUTARIES

The main tributaries of the Red River below the point of confluence of the Ottertail and Bois-de-Sioux rivers are: the Wild Rice, Sheyenne, Elm, Goose, Turtle, Forrest, Park, and Pembina Rivers on the North Dakota side; the Buffalo, Wild Rice, Red Lake, Snake, Tamarack, and Two Rivers on the Minnesota side; the Roseau, Rat, LaSalle, and Assiniboine in Canada. The headwaters of the Roseau River are in Minnesota.

Following is a list of the principal tributaries of the River in the United States with their drainage areas in square miles:

Pembina (N.D.-Man.)	3530 sq.mi.	Goose (N.D.)	1260 sq.mi.
Two Rivers (Minn.)	776 sq. mi.	Wild Rice (Minn.)	1440 sq.mi.
Tamarack (Minn.)	580 sq.mi.	Elm (N.D.)	460 sq.mi.
Park (N.D.)	1130 sq.mi.	Buffalo (Minn.)	1400 sq.mi.
Forrest (N.D.)	1000 sq.mi.	Sheyenne (N.D.)	7380 sq.mi.
Snake (Minn.)	1040 sq.mi.	Wild Rice (N.D.-S.D.)	2210 sq.mi.
Turtle (N.D.)	700 sq.mi.	Ottertail (Minn.)	1840 sq.mi.
Red Lake (Minn.)	5760 sq.mi.	Bois-de-Sioux (N.D.-Minn.)	1860 sq.mi.

NOTE: The difference between the total of the above and the total drainage area of 35,895 square miles at the border represents the drainage area of smaller tributaries not listed.

HYDROLOGY*

The records indicate that many floods occurred throughout the valley during the time of its early settlement. Considerable river traffic was carried on and the flow was seldom inadequate. During 1913, 1916, and 1919 serious floods occurred, probably caused in part by the newly built drainage ditches and other man-made changes in the natural drainage of the valley. During the period of record prior to 1920, the basin experienced a relatively wet cycle, after which a drouth cycle began to appear. Ground water levels receded until many underground supplies were no longer adequate. With one or two exceptions, the situation became more critical until 1930 when serious drouth conditions began. Stream flows decreased steadily during this serious drouth period.

In 1934 zero flows were recorded during the four months, July to October inclusive, at the Fargo gaging station. From 1929 to 1935 there were five periods aggregating 14 months when the flow at Fargo was zero.

CLIMATOLOGY

The climate of the basin is characterized by long cold winters and relatively short warm summers. Temperatures vary from -30 in the winter to 95 degrees Fahrenheit in the summer. Extreme temperatures of -50 and 110 degrees have been recorded. The mean annual temperature of the basin, based on the mean annual temperatures at recording stations in the area, is 38.7 degrees Fahrenheit. There is a geographical uniformity of climate because of the small altitude variation throughout the whole valley.

Prevailing winds are from a northwesterly direction. Rising to great heights in crossing the Rocky Mountains, they are mostly dry winds. The southeasterly winds coming from the Gulf of Mexico bring most of the rain. Fortunately the south winds prevail during the growing season which varies from 103 to 139 days. Throughout the valley the mean annual rainfall from available records of all stations is 20.11 inches; variation is from 16 to 34 inches. Average annual evaporation from water surfaces is approximately 36 inches. Annual runoff varies from 0.54 inches to 3.55 inches; the average for the basin is 1.25 inches.

ECONOMIC TRENDS

POPULATION

From 1890 to 1910 the population of the entire valley increased rapidly. It very nearly doubled, being 228,000 in 1890 and 443,000 in 1910. Since 1910 the increase has been slow; the 1930 population

*Hydrometric data are given in Appendix I.

was 489,000. The rural population has been declining since 1920; this decline has been but slightly more than compensated for by the increase in urban population. A decline is also noted in towns of less than 2500.

Urbanism in this area is advancing much slower than in other parts of the country. During the decade ending 1930, the urban population increased at a rate which was only two per cent greater than the total urban and rural rate for the United States as a whole.

The rural, urban, and total populations of the Red River basin by watersheds are given in Appendix IV, tables I to IV, inclusive.

AGRICULTURE

The primary industry in the Red River basin is agriculture. Grain farming is the most common type of enterprise despite recent trends toward diversification. Dairy and poultry products have undergone a marked increase in production during the last decade although grain crops, of which dark northern spring wheat is the most important, still have by far the largest monetary value. At the turn of the century 61 per cent of the entire land area of the basin was in farms and 72 per cent of this was such that it could be cropped. By 1930, 77 per cent of the entire land area was in farms and of this 92 per cent was improved. The remaining 23 per cent of unfarmed land is largely composed of swamp, muskeg, and peat lands which are not adaptable to farming; it includes also lake shore property used for recreational purposes.

INDUSTRY

Industries within the basin are composed of service industries and those industries necessary to the processing of various agricultural products. In 1930 there were 150 creameries serving the growing dairy industry, with an annual output of creamery products valued at $21,694,029. In addition, there were in operation one large and several small flour mills, one large and a few small meat packing plants, and one beet sugar plant. Service industries consist of machine shops, bakeries, foundries, print shops, etc. There are no industries within the basin besides the agricultural industries mentioned above that are producing to any extent for inter-territorial trade.

Regarding industrial employment, 38 per cent of the total Minnesota population were gainfully employed in 1930; 20 per cent were engaged in manufacturing and mechanical industries. In that portion of Minnesota which lies in the Red River basin, 36 per cent of the population were gainfully employed in 1930 of which only ten per cent were engaged in manufacturing and mechanical industries.

An important enterprise of the Ottertail Basin is the tourist trade. The wild life and recreation facilities of the Minnesota lake regions have been developed to a great extent within recent years.

STREAM DEVELOPMENT AND WATER PROBLEMS

During the early years of development in the Red River basin, the natural marshy land afforded relatively satisfactory flood control and stabilization of dry weather flow. The spring runoff and occasional summer storms were retarded in the upper reaches of the drainage basin and caused a continuance of flow during normal drouth periods of the summer and fall. With the expansion of agriculture and the cultivation of lands artificial methods of drainage were provided. Canals and ditches were constructed for drainage alone with little thought to control; this together with cultivation and deforestation resulted in increased flood flows and decreased low flows. The dry weather flows at present result largely from the issuance of ground water at the headwaters of the various tributaries.

Beginning in 1929 there followed several years of exceedingly low rainfall. This was accompanied by serious depletion of shallower ground water resources. The deeper ground waters, which were affected less, are highly mineralized and in most cases unsatisfactory for domestic use.

With the receding of useable ground waters during the drouth period some cities turned to the river for additional supplies. This made necessary the construction of water treatment plants and storage reservoirs.

Until very recent years practically all sewered cities on the river and tributaries discharged raw sewage. Most of the major cities now have provided some type of sewage treatment; however, treatment of many important industrial wastes remains to be accomplished. Very unsatisfactory pollutional conditions have existed for the past several years, especially during low flow periods. Usefulness of the river to both municipal and rural riparians has been greatly impaired by the combination of low flow and pollutional discharge. The bacterial and other organic loadings upon water treatment plants have at times exceeded the reasonable capabilities of modern purification processes. All but one of the larger cities depend upon the river as the source of public water supply.

Rural riparians have been affected acutely by the impairment to the quality of river water. Especially below Grand Forks, the farmers on and near the river are dependent on the stream for stock watering, irrigation, general household uses such as laundering and cooking, and even for drinking water. During the February 1938 study meetings were held at points below Grand Forks to hear complaints and gather information on the extent of dependence on the river as a source of water supply.

Eighty-nine farmers and residents were interviewed and detailed information obtained. Altogether, forty persons stated that they used melted ice from the river for cooking; of eighteen farmers who used the river as a source of drinking water, ten used it in the form of melted ice. Seventy-one farmers stated that they watered

from the river a total of 4296 head of stock, mostly cattle. Many farmers who were dependent on river water for stock watering stated that during winter months their cattle drank very little water; that normally heavy fed dairy cattle would bloat and become very sick, some of them dying. More detailed information on complaints and rural use of river water is contained in the 1938 report. A complete and detailed investigation of the river and contributed wastes was essential before a satisfactory and practical corrective program could be worked out.

SUBSURFACE WATER SUPPLIES

As pointed out above the loss of usable shallower ground water supplies created a serious problem. In order to obtain the greatest value from remaining usable shallow ground water supplies, relocation or readjustment of existing wells may be necessary in many cases. Through geological investigation additional subsurface supplies may be located. Further, the location and mode of occurrence of both satisfactory and unsatisfactory supplies may be determined and the best method of obtaining the desirable supplies forecast. Water strata of unsatisfactory mineral characteristics may have to be cased out in some localities. With the exception of the larger cities in the valley practically all communities and rural settlements obtain water for domestic purposes from subsurface sources.

STORAGE

The National Resources Committee in their report on the Red River dated August 1937 discussed the necessity of flood flow storage. It was brought out that the detailed solutions which go to make up a comprehensive plan must of necessity be closely coordinated because of the scarcity of water for municipal and industrial use. The headwaters of the streams, it was stated, afford the best opportunities for storage but in addition thereto an extensive channel clearing and channel straightening program must be incorporated to convey the water from storage to the towns below with minimum loss.

The main proposed storage projects consist of control works on the Red Lakes and several small control dams in the Ottertail Basin. For the Sheyenne River there is the proposed Bald Hill Reservoir above Valley City, North Dakota and many small projects throughout the remaining part of the valley. No additional storage reservoirs are recommended for the Red River proper as losses due to evaporation are likely to be greater than the benefits derived from storage. Larger types of dams, although beneficial from a standpoint of oxygen replenishment by aeration, are not in accord with the general plan. The existing structures may even be lowered or removed entirely except where needed as water intakes. Other features of the program which must be taken into consideration are subsurface

water supplies, sewage treatment, flood control, wild life conservation, and diversion from other water sheds.

SEWAGE TREATMENT

Sewage treatment by larger municipalities came about first as a result of an injunction by affected riparians. Later, lawsuits resulted in the installation of sewage and waste treatment facilities. All but a few of the larger municipalities and many of the smaller ones have installed some form of sewage treatment. Extensive industrial waste treatment facilities have been installed at West Fargo. Some important industrial and municipal wastes are being discharged untreated at present.

One of the most important economic problems to be solved is that of securing a practical balance between the cost of constructing or improving and operating sewage treatment works and the cost of constructing and operating storage or diversion works to supply dilution water. The problem of attaining this balance depends to a great extent on the degree of stream cleanliness that is to be achieved.

FLOOD CONTROL

Flood control will be effected to a great extent by the completion of storage projects. Peak floods, however, may be controlled to a great extent only by projects similar to the one under construction at Lake Traverse. Wild life conservation projects may accompany a large percentage of all these undertakings as they are essentially storage at the head waters.

DIVERSION

In recent years considerable attention has been focused on the diversion of water from the Missouri River to the Red River Basin and other watersheds. From a water supply and sewage disposal standpoint there is little doubt of the great value which would result from this project. In a report prepared by the North Dakota State Department of Health and the Office of the State Engineer in 1939 the yearly benefits to water and sewage capitalized at five per cent were estimated at approximately fifteen million dollars. Other benefits computed by the Commission and capitalized at five per cent, exclusive of recreation, water power, and general increase in land values, raised this figure to thirty-eight million dollars. The entire cost of the project was calculated to be approximately thirty-nine million dollars, and provided for the diversion of about 600 c.f.s. A 996,000 acre foot storage reservoir would be constructed at the headwaters of the Sheyenne River with approximately one-third of its capacity available for diversion to Devils Lake or to the James River, the remainder supplementing the flows of the Sheyenne. According to the plan, a portion of this flow would be diverted to the Red River above Fargo. A detailed report by the U. S. Army Engineers on the proposed diversion is now nearing completion.

SURVEY PROPER

SAMPLING STATIONS

The climatic conditions of the Red River basin necessitated the careful selection of sampling stations. During the winter months considerable difficulty was anticipated because of the impassability of snow blocked roads by automobile. As a result stations were located at strategic points that were near main traveled highways. Red River sampling stations selected in previous surveys were utilized with one exception (Station 5 added) in this study.

Twelve sampling stations were maintained on the Red River proper. Eleven sampling stations were maintained at the mouths of the tributaries and one station was maintained at the East Grand Forks Beet Sugar Factory effluent ditch just above its point of discharge into the Red River. All tributaries were sampled whenever they were flowing.

The following tabulation shows the location of the sampling stations in their order upstream from the International Boundary. All river stations were designated by numbers running in order from the International Boundary south and the stations on the tributaries were designated alphabetically starting at the International Boundary. (See map at beginning of report.)

Riverside Park Dam at Station 6 in Grand Forks. A typical Low Overflow Dam.

Red River and tributary sampling stations showing location, miles south of International Boundary, etc. (Mileages taken from U. S. Department of Agriculture Bulletin No. 1017—Report on Drainage, Etc. by Simons & King.) Tributary sampling stations are all on highway bridges within a few miles of the mouths of the streams. Distances given are from mouths of tributaries to International Boundary.

Station	Mile No.	Location	Remarks
A	2.8	Mouth of Pembina River. Highway bridge in City of Pembina	Receives Cavalier (40 mi.) and Walhalla (60 mi.) sewage.
1	3	Highway bridge at Pembina	
B	20	Two Rivers	Receives Hallock (12 mi.) and Lancaster (30 mi.) sewage.
2	53	Highway bridge at Drayton	
C	65	Tamarack River	
D	67	Park River	Receives Grafton (24 mi.) and Park River (50 mi.) sewage.
E	75	Snake River	Receives Warren sewage. (30 mi.)
3	77	Directly East of Grafton	
F	88	Mouth of Forrest River	
4	116	Highway bridge at Oslo	
5	129	Directly East of Manvel	
6a	138	Below Grand Forks	Includes all wastes discharged at Grand Forks—East Grand Forks
6	141	Above West End of Riverside Park Dam in Grand Forks	Receives East Grand Forks sewage and Sugar Beet wastes. Dam 10 Feet High.
G	141.2	East Grand Forks Beet Sugar Plant Outfall	
H	143	Red Lake River	Receives Crookston (45 mi.) Thief River Falls (117 mi.), Red Lake Falls (83 mi.), Fosston (123 mi.) sewage. Overflow Dam (3 Feet) between sampling Station and mouth.
7	145.7	Above Grand Forks	At ski slide in Lincoln Park.
8	180	Highway bridge at Climax	
I	203	Goose River	Receives Hillsboro (15 mi.) and Mayville (50 mi.) sewage.
9	220.4	Highway bridge at Halstad	Halstad sewage outfall less than one mile above station.
J	225	Minnesota Wild Rice River	Twin Valley sewage (82 mi.), Mahnomen sewage (118 mi.)
10	261.4	Highway bridge at Georgetown	
K	262.5	Buffalo River	Hawley sewage (36 mi.), Barnesville sewage (45 mi.)
L	273	Sheyenne River	Armour's Packing Plant at West Fargo (20 mi.). Also other cities at considerable distance.
11	286	Highway bridge below Fargo sewage treatment plant	Fargo sewage—¼ mile above; Moorhead sewage—6 miles above. 6′ overflow dam—7 miles above.
12	298	Fargo Water Works intake	½ mile above 7-foot dam.
	303	3-Ft. overflow dam	
	329	9-Ft. overflow dam	
	341	9-Ft. overflow dam	
	394		Wahpeton & Breckenridge sewage.

COLLECTION OF SAMPLES

Samples were collected weekly on Red River stations south of the International Boundary from November 1, 1938 to July 1, 1939 and from September 1939 to December 14, 1939. One complete sampling trip was made in August 1939, two in January, one in February, and one in March 1940. Samples collected from tributaries were obtained regularly during periods of perceptible flow.

In order to balance laboratory work with field work and provide for reasonable hours, the area normally was sampled in three stages making one trip every other day as follows:

1. All stations north of Grand Forks, starting with Station 5.
2. Stations in Grand Forks area (6, 7, and H) and beet sugar plant wastes, Grand Forks sewage treatment plant, State Mill, Packing Plant, etc.
3. Stations from Grand Forks south, starting with Station 8.

(Sampling was staggered to avoid sampling the same point on the same day of each week.)

Chemical and bacteriological samples were taken in a sampler so designed that a bacteriological (125 cc), a dissolved oxygen (250 cc), and a biochemical oxygen demand sample (2 liters) could be taken at one time; enough was left over from the B.O.D. sample to make the other necessary chemical and physical determinations. One sample was taken at a point in the channel at mid-depth.

Samples were taken from bridges in most cases. During winter, holes were chiseled through the ice and the sampler lowered into the stream from the ice surface. In the fall and spring when it was unsafe to walk on the ice, skiis were used. A light boat carried on top of the car was used in spring and fall and during open water periods where samples could not be obtained from bridges, docks, etc. Occasionally, samples were obtained by casting the sampler out into the flowing stream. Several trips were made by boat downstream from Grand Forks in an effort to trace the oxygen sag curve. No appreciable sag was observed between Grand Forks and Oslo (Station 4) during the spring and early summer higher flow periods. Algal activity was believed to be an important influence. Later, when the flow decreased, portions of the stream were too shallow to permit use of a boat and outboard motor for such work.

All samples were transported by automobile and brought to the laboratory for examination on the same day they were collected.

LABORATORY PROCEDURE

Routine laboratory procedure consisted of determining the nitrites, turbidity, pH, initial dissolved oxygen, and the 5-day biochemical oxygen demand at 20°C.

Bacteriological examination consisted of making an estimate of coliform organisms by planting triplicate portions of each of four geometric dilutions in standard lactose broth and incubating for 48

hours at 37°C. The highest dilution showing gas formation was then transferred to standard brilliant green bile broth and incubated at 37°C. for 48 hours. Gas production in brilliant green bile would then be considered a positive confirmation of the coli-aerogenes group; otherwise the next lowest dilution would be taken for positive. However, in the event only one or two lactose broth tubes of the highest dilution were positive, the next lowest dilution was also transferred to standard brilliant green bile broth for confirmation. This procedure is a slight variation from that recommended in Standard Methods of Water Analysis, Eighth Edition, but seems entirely satisfactory when it is considered that confirmation was obtained in all but a few cases during the course of the survey. The most probable number was then determined by referring to a table.[1]

All other determinations were made in accordance with Standard Methods for the Examination of Water and Sewage, Eighth Edition, except that in the presence of nitrites the Sodium-Azide modification[2] of the Winkler method for the determination of dissolved oxygen was used after February 1939. Samples for the determination of biochemical oxygen demand were brought to room temperature and saturated with oxygen by shaking in a half full bottle. This same procedure was used for both unsaturated and supersaturated samples. Whenever dilution of the river water samples was necessary, seeded bicarbonate dilution water was used.

Several long-time B.O.D. determinations were made on river water from most of the Red River stations at both 0°C. and 20°C. At first, the 0°C. incubations were kept under the ice in a creek near the laboratory. Later, 0°C. incubation temperatures were obtained by pumping water from the presedimentation tank of a water plant through a water bath incubator to waste. Constant temperatures of 0°C. were maintained without difficulty.

Bicarbonate dilution water was used in all B.O.D. determinations on industrial wastes except on the sugar beet wastes. Several types of dilution water were used in the B.O.D. determinations of this waste; formula "C"[3] phosphate dilution water gave the most satisfactory results and was adopted for this determination.

Examination of samples from representative river and tributary stations for mineral content and organic nitrogen content was made during ice coverage in 1939.

ICE COVERAGE

In the fall of 1938 the River was completely ice covered on the twenty-third of November excepting at Station 6 (just above Riverside Dam at Grand Forks) and Station 11 at Fargo, which stations stayed open all winter. Most of the river was ice covered

[1] M.P.N. table compiled from McCrady's Formula and Tables.
[2] Altzburg Modification Recommended by C. C. Ruchhoft.
[3] Volume 48, No. 24, Public Health Reports, Page 683, Footnote 1.

about a week before this. From January to spring break-up the ice had a thickness of about 24 to 26 inches; the thickest ice appeared at northerly stations. The break-up occurred between the twenty-second and twenty-seventh of March on the stations above Grand Forks. The time of ice coverage above Grand Forks varied from 120 to 134 days and below Grand Forks from 132 to 139 days.

Because of the unusually warm weather in the fall of 1939, complete ice coverage occurred from 15 to 41 days later than it did in the fall of 1938. Complete ice coverage occurred on about the tenth of December on the portion of the river below Grand Forks and on the twenty-sixth of December on the portion of the river above Grand Forks.

The river was still ice covered on the twenty-third of March 1940 and no samples were collected after that date. However, some water had flowed over the ice at that time at some of the stations. The following is a tabulation of the observed dates of ice coverage and break-up at the various stations.

DATES OF ICE FORMATION AND SPRING BREAK-UP

	1938–1939				1939–1940		
Station[1]	Ice First Appeared	Complete Ice Coverage	Spring Breakup	Days of Ice Coverage	Ice First Appeared	Complete Ice Coverage	Spring Breakup
12	Nov. 14	Nov. 22	Mar. 22 to 27	120	Nov. 28	Dec. 20	After Mar. 23
11	Open all winter				Open all winter		
L	Nov. 14	Nov. 30	Mar. 22 to 27	112	Nov. 28	Dec. 26	After March 23
K	Nov. 14	Dec. 14	Mar. 22 to 27	98	Nov. 28	Dec. 20	
10	Nov. 14	Nov. 15	Mar. 22 to 27	127	Nov. 28	Dec. 26	
J	Nov. 14	Dec. 14	Mar. 22 to 27	98	Nov. 28	Dec. 26	
9	Nov. 14	Nov. 15	Mar. 22 to 27	127	Nov. 28	Dec. 26	
8	Nov. 14	Nov. 22	Mar. 22 to 27	120	Nov. 28	Dec. 20	
7	Nov. 10	Nov. 15	Mar. 29 to Apr. 3	134	Nov. 29	Dec. 13	
H	Nov. 15	Nov. 15	Apr. 10 to Apr. 20	144	Nov. 28	Dec. 20	
6		Nov. 29	Mar. 29 to Apr. 3	120	Dec. 9	Dec. 20	
5	Nov. 16	Nov. 23	Apr. 6	132	Nov. 1	Dec. 10	
4	Nov. 9	Nov. 16	Apr. 6	139	Nov. 1	Dec. 10	
3	Nov. 9	Nov. 16	Apr. 6	139	Nov. 1	Dec. 10	
2	Nov. 9	Nov. 16	Apr. 6	139	Nov. 1	Dec. 10	
1	Nov. 9	Nov. 16	Apr. 6	139	Nov. 1	Dec. 1	

[1]Tributary stations not listed had no flow during ice coverage period.

CLASSIFICATION OF SEASONS

In portions of this report data and interpretations have been presented on both a monthly and a seasonal basis. The purpose of seasonal classification is to show trends over longer periods of time

under conditions which remain essentially the same. Three seasons have been chosen and are defined as follows:

A. **Winter Critical Season** (Dec. 1, 1938 to April 1, 1939) was taken to include that portion of the winter from the time the dissolved oxygen content approached zero to spring break-up. Since these conditions do not occur at the same time at all stations on the river a single winter critical season boundary cannot be taken which will be entirely accurate for each station.

B. **Spring High Flow Season** (Apr. 1, 1939 to July 1, 1939) was taken to include the high water season occurring during and after spring break-up until the time the river approached the usual summer stage.

C. **Summer Critical Season** (Aug. 1, 1939 to Oct. 1, 1939) was taken to include the period of low flows at summer temperatures.

ANALYTICAL DETERMINATIONS and INTERPRETATION

I. CHEMICAL AND PHYSICAL DETERMINATIONS

1. Dissolved Oxygen. (D.O.)

Regular weekly determinations of dissolved oxygen were made at all Red River and tributary stations south of the International Boundary, except when frozen to the bottom or when not flowing, during the eight months from November 1, 1938 to July 1, 1939, the period of time for which the investigation was originally set up. Sampling was continued on the Red River and some tributaries at irregular intervals from July 1, 1939 to March 21, 1940 in order to obtain additional necessary data.

In Figures 2 and 3, the results of all dissolved oxygen determinations on the Red River and tributaries have been plotted by stations; every dissolved oxygen determination made at these stations during the 17-month period from November 1939 to March 1940, is shown. Biochemical oxygen demand is shown similarly in these graphs.

Figures 4 and 5 show the dissolved oxygen trend as monthly averages expressed in terms of per cent saturation. Monthly averages of 5-day 20°C. B.O.D.'s are also plotted on the graph in order to present a relative picture of the amount of oxygen required and the amount available.

Monthly averages of dissolved oxygen, expressed as p.p.m. and as per cent saturation, are shown for Red River and tributary stations in Tables IV, V, VI, and VII. In interpreting dissolved oxygen values observed, it should be remembered that samples were collected during the day and that the effect of algal activity may be considerable. Supersaturation to the extent of 60 per cent was

observed repeatedly during the early winter open water period of 1939-40.

Discussion of Dissolved Oxygen Observations in Chronological Order.

Referring to Figures 2 and 3, it may be seen that the dissolved oxygen content at most stations approached the saturation value of approximately 14 parts per million just prior to ice coverage in 1938. The oxygen sag is evident below Fargo-Moorhead, and very pronounced below Grand Forks-East Grand Forks.

With the onset of ice coverage, a rapid drop in dissolved oxygen and failure to recover is noted below Fargo and below Grand Forks. Dissolved oxygen content dropped to zero or near zero in the following approximate time intervals after ice cover formed.

Below Fargo:	**Below Grand Forks:**
Station 10 — 6 weeks	Station 4 — 3 weeks
9 — 6 weeks	3 — 2 weeks
8 — 4 weeks	2 — 2 weeks
	1 — 3 weeks

Following this December critical period, a slight increase in dissolved oxygen was noted at Stations 10, 9, and 8 below Fargo. This may be attributed to a four-fold increase in stream flow at Fargo during January and February. At Station 12 above Fargo the lowest dissolved oxygen content observed throughout the winter of 1938-39 was approximately 6 p.p.m. The reoxygenation provided by three dams above Station 12 is the most probable explanation. Likewise, the dams in Fargo and the open water from the Fargo sewage treatment plant outfall to a point below Station 11, account for the appreciable dissolved oxygen observed at Station 11 throughout the winter.

A low overflow dam on the Red Lake River just prior to its confluence with the Red River and a higher overflow dam on the Red River a short distance downstream from the confluence, provided considerable aeration at these points. These dams, together with the open water stretches in and below Grand Forks, provided sufficient aeration to maintain some dissolved oxygen continuously as far below Grand Forks as Station 5.

Subsequent to the termination of operations at the beet sugar plant in late December, reappearance of one or two p.p.m. of dissolved oxygen at Stations 4, 3, 2, and 1 was observed.

Stream flow during the most critical winter period (January, February, and part of March, 1939) averaged approximately 100 c.f.s. at Fargo and 235 c.f.s. below Grand Forks. Evidence of septic conditions in the river was much less pronounced than during the previous winter critical period when stream flows were from one-third to one-half of these values.[1] The point of significance is that

[1] Joint investigation by North Dakota and Minnesota Departments of Health, February 1938.

even with winter stream flows of reasonable magnitude, very unsatisfactory conditions existed under ice coverage because of excessive organic pollution.

Following spring breakup, high stream flows and open water conditions brought about an immediate improvement in dissolved oxygen content of the river. Reasonably satisfactory dissolved oxygen conditions existed during the high flow period of spring and summer.

The 1939 summer critical period appeared somewhat later than normal; average monthly stream flows dropped from 85 to 15 c.f.s. at Fargo and from 460 to 144 c.f.s. at Grand Forks in August. Flows decreased further to 3 c.f.s. at Fargo in September and increased from 144 to 216 c.f.s. at Grand Forks. At all points except immediately below Fargo and Grand Forks, dissolved oxygen was well in excess of oxygen demand during the critical summer months of August* and September. Dissolved oxygen content fell to nearly zero at Station 11 below Fargo the first week in September.

In the winter of 1939-40 complete ice coverage was delayed until the latter half of December. This condition permitted a longer period of observation under low-temperature open-water conditions. Stream flows at Fargo in November and December were slightly less than in the same months of the previous year. Dissolved oxygen content in p.p.m. was slightly higher because of open water conditions. Also, during these same two months the stream flow at Grand Forks was 300 c.f.s. or about 50 per cent greater than the 1938 flow of 200 c.f.s. This higher flow may have been responsible in part for the observed increase of about 50 per cent in p.p.m. B.O.D. That is, an increase in stream velocity may cause suspended material which would settle out at the lower velocity to be carried in suspension. The velocity difference is approximately 20%.

At no point during these two months was the dissolved oxygen content observed to be zero in the entire stretch of river from Fargo to Pembina. The ability of the stream to maintain satisfactory dissolved oxygen conditions under open water and low temperature conditions, even with heavy organic loadings, is indicated especially below Grand Forks. Supersaturation existing at Stations 7 and 8 in November and December indicated appreciable algal activity at low temperatures, with open water. It is not known whether the supersaturation persisting at Station 7 for approximately one month after ice coverage was a result of algal activity before or after ice coverage or whether it resulted from a combination of both. Following ice coverage, depletion to zero of dissolved oxygen resources was observed at Stations 10, 9, 8, 3, 2, and 1 within approximately one month after ice cover. Sampling was terminated prior to the 1940 spring breakup.

* Only one sampling trip made in August 1939.

2. Biochemical Oxygen Demand

Samples for B.O.D. determination were taken at the same time as dissolved oxygen samples; results of determinations are shown in Figures 2 to 6 inclusive. Separate tabulations of monthly averages are shown in Tables VIII and IX. The points of heaviest pollution and the variation in loading are indicated by the graphs and tables. The surplus or deficit of dissolved oxygen over 5-day 20°C. B.O.D. is shown by stations in Figures 2, 3, and 4.

With the exception of the winter critical period and the late summer critical period, the dissolved oxygen is generally in excess of the B.O.D. A more detailed presentation of the oxygen relationships is included in the section on Stream Loadings and Oxygen Requirements. Sludge deposits appear to exert an appreciable demand; this is most noticeable under ice coverage conditions.

3. Other Determinations

Nitrites, temperature, turbidity, and pH were determined routinely at the same time as dissolved oxygen and B.O.D. Tabulations of monthly averages are included in the report as Tables X to XVII inclusive.

Nitrites.—This determination was made on regular river samples primarily to indicate the dissolved oxygen procedure necessary. Nitrite concentrations were greatest below Fargo-Moorhead; the sewage treatment plants at both of these municipalities include trickling filters. Nitrites persisted greater distances downstream from Fargo-Moorhead during the ice coverage period than at any other time of the year. Below Grand Forks nitrites were observed in significant amounts only under low temperature conditions. A tabulation of monthly averages of nitrite determinations is included as Tables X and XI.

Temperature.—Monthly averages of water temperatures for all Red River stations are shown in the tables XII and XIII. At least four full months of 0°C. water temperature is indicated at most stations. Maximum monthly summer temperature averages are slightly above 20°C.

Turbidity.—The purpose of making turbidity determinations was to provide an approximation of the suspended solids content. Highest turbidities were coincident with highest flows (following spring break-up); lowest turbidities occurred in the late fall and winter months, the minimum being reached just prior to spring breakup. Sufficient correlation was observed between turbidity and oxygen demand to be of value in determining B.O.D. dilutions during periods of high turbidity. A direct relation between stream flow and turbidity over the entire year is not apparent; lower turbidities were observed in winter than in summer for the same stream flow. The average monthly turbidities for each river station are shown in Tables XIV and XV.

pH.—A distinct variation between open water and ice coverage conditions was evident at most stations on both the main river and its tributaries. Highest pH values (8.5) were associated with high dissolved oxygen and low B.O.D. The pH during ice coverage averaged from 0.2 to 0.7 units lower than during the open water period. Maximum monthly average variation was 1.0 pH unit. See Tables XVII and XVIII.

Chemical Analyses.—Two series of chemical analyses were made at some of the representative stations. Tabulations of results are made in Table XVIII and are arranged to show contrast between ice coverage and open water conditions. No particular significance can be attached with only two samples from each point, but the general quality of the water at the time samples were taken is indicated. Since some oxygen was present at most stations when the set of samples was obtained under ice coverage conditions, variations in organic constituents are likely to be as much a result of flow changes as a result of ice coverage.

II. BACTERIOLOGICAL EXAMINATION

Samples for coliform organism determinations were taken at regular sampling stations at the same time other samples were obtained. Examinations were made in the Public Health Laboratory in Grand Forks by the regular laboratory personnel. Standard Methods' procedures were followed except as previously noted. Estimates of most probable numbers were made from the results of confirmation tests on triplicate tubes in a geometric series of four, using McCrady's Formula and Tables.

The figures entered in Tables XIX and XX inclusive are monthly arithmetic averages of individual sample results. In the early part of the study, some dilutions set up were too low; this accounts for the large number of indeterminate results. The numbers following the asterisks in the Tables indicate the number of indeterminate results of magnitude shown by footnotes.

Points along the main stream where pollution is received are clearly indicated. Principal among these are the Fargo-Moorhead area (Sta. 11), and the Grand Forks-East Grand Forks area (Sta. 6). The effect of the beet sugar plant at East Grand Forks is clearly evident during its operation. Results at Station G (beet plant outfall) indicate the tremendous pollutional effect of this industrial waste, which becomes progressively stronger as the operating season proceeds. The effect on the stream is most detrimental because the strongest waste is discharged during ice coverage.

Extremely high coliform organism concentrations at and below points of pollution were noted; the concentration decreased progressively downstream. Average concentrations at water works intakes (Fargo — Sta. 12 and Grand Forks — Sta. 7) were not in

excess of the treatment plants' capabilities with respect to coliform organism loadings.[1] (See Figures 12, 13, and 14.)

III. BIOLOGICAL DATA (by Minnesota State Board of Health)

Samples of bottom sediment were collected at regular sampling points along the Red River from a point immediately above Fargo and Moorhead to the Canadian Boundary.[2] In the field, collections of the sediment were made through the ice. The sample was obtained by using a Petersen dredge and the material collected was immediately concentrated by sifting through a No. 30 U. S. standard sieve. Formalin was used as preservative and the concentrated material sent to the laboratory for examination. The procedure followed in the laboratory was that described in the eighth edition of Standard Methods of Water Analysis.[3] The summarized results obtained in the laboratory examination appear in Tables I — 1 to III — 2, a graphical representation of the data in Fig. 1.

The study of the bottom fauna showed that clean-water forms were scarce in that portion of the Red River included in this survey. This is in accordance with earlier observations made in 1931-1933 and in 1939. With minor exceptions, conditions were so similar that many of the statements made in the earlier reports apply in all essentials to the present survey.

As indicated in the 1933 report, pollutional forms were predominant at most points with a limited number of clean-water forms present in some of the samples at Georgetown (Sta. 10), Halstad (Sta. 9), Oslo (Sta. 4), and Drayton (Sta. 2). At Olso the clean-water forms were partially decayed, indicating that they had succumbed to the adverse winter conditions which existed there. Their presence in this sample, therefore, is merely evidence that this section of the stream is suitable for less tolerant forms during the warmer months when an ice cover does not exist. The same condition existed last year (1938) during the winter period and remnants of clean-water organisms were also found at that time.

The marked predominance of pollutional forms in slack water areas above dams, referred to in the 1938 report, was again apparent in samples taken above the dams at Fargo and at Grand Forks. The tendency for large quantities of organic matter to settle in the quiet water behind these dams is largely responsible for this condition.

Samples obtained north of Oslo during the 1938 survey contained a number of clean-water organisms which up to that time had survived unfavorable conditions. This year collections of the sediment were made about a month later than last year, a fact which probably accounts for the absence of clean-water forms in all but one

[1] Studies of the Effect of Water Purification Processes, H. W. Streeter, Public Health Bulletin.

[2] The field work, including collection and concentration of samples was done from March 16 to 23.

[3] S. M. W. A. Am. P. H. Association 1936.

of the samples taken in this area. (See Fig. 1.) As indicated in the 1938 report, delay in sampling may allow certain soft-bodied organisms which have died earlier in the season to completely disappear by disintegration. For this reason, and because the total winter effect upon the bottom-dwelling fauna is most evident just before the final spring "break-up", it is believed that the samples taken this season are most representative of the winter condition of the stream. Apparently clean-water forms are established in this part of the stream each year only to be eliminated during the ensuing winter when the zone of active decomposition extends downstream.

The Red Lake River, as the largest tributary in this section, is of considerable interest. Samples taken from this stream are almost identical with those taken last year and a considerable degree of upstream pollution, artificial and natural, is indicated.

Nannoplankton organisms were more numerous than observed to be last year but only reached a maximum of 447,000 as compared to a maximum of $12\frac{1}{2}$ million organisms observed during the winter period of 1933. The maximum this season occurred immediately below Moorhead and Fargo and below Grand Forks.

Increases in organic pollution are especially favorable to the growth of certain species of Nannoplankton, such as Oscillatoria and other bluegreen algae. In this connection it is interesting to note that Oscillatoria geminata was especially abundant below the larger municipalities where a marked fertilizing effect might be expected. Protozoa, which are also abundant where a polluted condition obtains, were abundant at almost all stations. This is quite in line with the general evidence of pollution through the whole area.

In general the biological data, including both plankton and bottom fauna, indicate that pollution is extensive during the period of the winter when ice covers the stream, and that it is evident throughout the entire portion of the stream included in the survey.

STREAM LOADINGS AND OXYGEN REQUIREMENTS

STREAM LOADINGS

The two major points where pollution is discharged into the section of the Red River under observation are the Fargo area (between Stations 11 and 12) and the Grand Forks area (between Stations 7 and 5) the latter receiving the larger portion. Since there is such a great difference in flow in the two sections of the stream above and below Grand Forks, no direct comparison of the stream loadings can be made from the B.O.D. expressed in parts per million. A tabulation of 20°C. 5-day B.O.D. in pounds per day is included in the Base Data tables XXI, and XXII. These values do not represent the actual oxygen requirements of the stream because the time of flow and the rates of deoxygenation at the prevailing temperature have not been taken into consideration. How-

ever, these values are included because they represent base data expressed in standard terms; they are monthly averages of actual determinations.

Temperature, time of flow and rate of deoxygenation are taken into account in Table XXIII for the 1938-39 winter ice coverage period and in Table XXIV for the 1939-40 winter ice coverage period. For stations below Grand Forks, five-day 20°C. B.O.D. values have been converted to 0°C. B.O.D. values using an incubation period equal to the time of flow from each of these stations to Lake Winnipeg. For stations above Grand Forks, the 0°C. B.O.D. incubation period is taken as the time of flow from each of the stations to Station 6 because at this point the pollution, dilution and aeration change the oxygen relationship entirely.

A comparison of the 5-day 20°C. B.O.D. with the dissolved oxygen, both expressed in pounds daily (Quantity Units), is shown graphically by station and season in Figures 7, 8 and 9. These same quantity unit values of B.O.D.'s for the winter critical season (A) and the summer critical season (C) are shown in Figures 10 and 11 together with the principal sources of pollution.

In Figures 10 and 11, the major tributaries, municipalities, and industries are plotted to show their average seasonal contribution in pounds of 5-day 20°C. B.O.D. daily. It should be noted that the increase, or decrease in B.O.D., as the case may be, between any two stations should approximate the B.O.D. of the entering wastes minus the natural reduction of all wastes effected between these stations. A relative picture is therefore shown, although further explanation is necessary for such apparent discrepancies as are indicated on Figure 10 in the Fargo-Moorhead area.

Fargo-Moorhead Area

Little correlation between the observed B.O.D. of wastes entering in this area (above Station 11) and that found in the stream can be noted. For example, the oxygen demand of the wastes from Fargo and Moorhead as measured and according to treatment plant records is approximately 1400 pounds per day. (See Table V, Appendix II). Therefore, it would be expected that the observed B.O.D. at Station 11 would be approximately 1400 pounds greater than that at Station 12 (above Fargo) since no other drainage or waste of significance enters between these two points. However, the observed increase at times exceeded this amount and at other times was less. The table following shows the monthly variation together with the corresponding stream flow.

Net Increase in Five-day 20°C. B.O.D. in Pounds Daily Between Stations 12 and 11

Month	1938 Nov.	Dec.	1939 Jan.	Feb.	Mar.	Apr.	May	June	Aug.	Sept.
Sta. 11	1627	1661	6033	2644	23270	19965	5415	4155	679	385
Sta. 12	559	446	1152	936	10031	8253	2957	3062	496	135
Gain	1068	1215	4881	1708	13239	11712	2458	1093	183	250
c.f.s. Flow	23	25	97	102	743	710	219	135	18	5

From the above tabulation, it is noted that for low stream flows a much lower increase in B.O.D. than the value of 1400 pounds was observed and that during high stream flows a much higher increase was found. Possible reasons may be the extreme variation in quantity and velocity of flows, the effect of sedimentation during lower flows and subsequent scouring of sludge banks during higher flows, and the difficulty of obtaining a representative sample at Station 11 due to the proximity of the Fargo sewage outfall. Various other indeterminate or non-apparent factors may also be involved in this discrepancy.

Excluding March and April, the average increase in B.O.D. for the remaining months probably would approximate the value of the entering wastes, if the low flow months of July and October were taken into consideration. (No samples were taken during these months.) The B.O.D. in p.p.m. of the river above Fargo was found to be relatively constant. It would seem improbable that the high values of March and April were, in any measure, a result of land surface drainage from the relatively small area between the two stations. However, the by-pass arrangement of the combined storm and sanitary sewers of Fargo, may exert an appreciable effect during spring runoff.

Fargo to Grand Forks Area

The Sheyenne (Station L) and Buffalo (Station K) Rivers join the Red River between Stations 10 and 11 which are 25 miles apart. The pollution load of the river at Station 10 should, therefore, approximate the total of that found at Stations 11, L and K. The following table compares the combined pounds of five-day, 20°C. B.O.D. for Stations 11, L and K with that at Station 10. Stream flows are also shown.

Comparison of Combined B.O.D. of Stations 11, L and K with that Found at Station 10

Month	1938 Nov.	Dec.	1939 Jan.	Feb.	Mar.	Apr.	May	June	Aug.	Sept.
Total Lbs. B.O.D. Sta. 11, L, & K.	2024	1806	6303	2912	28774	35436	6884	5703	1045	595
Total Lbs. B.O.D. Sta. 10	778	328	1436	3774	20315	42174	4666	6444	1283	321
Flow at Sta. 11	23	25	98	102	743	711	218	135	17	5.2
Flow at Sta. 10	45	38	95	102	855	1420	320	234	25	9

Excepting for August, when only one sample was taken, and January, the months with flows of 90 second feet or more showed a smaller per cent of difference than those months with flows below 90 second feet.

During the high flow period from April to June, the pounds of 5-day 20°C. B.O.D. in the river increased progressively downstream from Station 10 to Station 8, but dropped between Stations 8 and 7. The influence of the reservoir created by the dam at Grand Forks should be taken into consideration in this latter case.

During the summer critical months, some drop in the B.O.D. was noticed progressively downstream. Except during months of very low flow, the B.O.D. added by the tributaries is relatively small. During times of low flow in the Red River, the Sheyenne River contributes a fairly high per cent of the total B.O.D. in the river. The flow in the Sheyenne during such times may be as great or greater than that found in the Red River.

Grand Forks Area and the Portion of River Between Grand Forks and the International Boundary.

In the section of the river below the confluence of the Red River and the Red Lake River, the quantity of B.O.D. is considerably greater than that in the portion of river between Fargo and Grand Forks because of the greater quantity of contributed wastes and the increased flow. The percentage difference in loading between these two portions of the River is most pronounced during the fall and winter season when the beet sugar plant is in operation. The effect of the beet sugar plant wastes, and their settling characteristics are indicated in the table following:

Comparison of Combined B.O.D. of Stations 7 Plus H with the B.O.D. at Station 6 and at Station 5.

MONTHLY AVERAGE POUNDS— 5 DAY, 20°C. B.O.D.

Mo.	1938 Nov.	Dec.	1939 Jan.	Feb.	Mar.	Apr.	May	June	Aug.	Sept.	Oct.	Nov.	Dec.
Sta. H & 7	2579	2246	1804	1643	3973	73341	15124	11150	2634	6132	8023	9238	2921
6	19494*	18699*	3495	2844	4806	102970	15267	8162	3059	4495	22725*	36383*	36571*
5	10157	9302	6853	4385	7500	87890	13865	8595	2548	4120	13707	22810	20360
6-5	9337	9278				15080	1402	·	511	375	9018	13573	16211
Flow at 7	59	59	78	99	274	2450	458	336	38	16	24	41	28
Flow at 6	190	199	237	229	455	3126	912	687	118	225	334	332	314

The above tabulation shows that during the months of November and December 1938 and October, November and December 1939, the water gained about 16,000 to 33,000 pounds of B.O.D. per day between the point of confluence of the Red Lake and Red Rivers (Sta. H and 7) and Station 6. During these months the principal sources of pollution in this section of the river were the beet sugar

*Beet Sugar Plant operating.

plant and the City of East Grand Forks. The actual average oxygen demand of these wastes expressed as 5-day 20°C. B.O.D. was about 24,400 pounds for the beet sugar plant and about 690 pounds for East Grand Forks.

The tabulation also shows that during the months referred to above there was a decrease in pounds of B.O.D. from Station 6 to Station 5 of 9,000 to 16,000 pounds. Approximately 1,750 pounds of B.O.D. (City of Grand Forks—1340, Packing Plant—335, and Flour Mill—73) are discharged daily into the river just below Station 6; thus, an actual total reduction of 11,000 to 18,000 pounds of B.O.D. occurred between Stations 6 and 5. During the three months following the close of the beet sugar plant, there was an increase in pounds of B.O.D. from Stations 6 to 5 in excess of the 1750 pounds added by industrial and municipal wastes.

Analysis of the foregoing data seems to indicate that the following deductions offer at least a partial explanation of the observed phenomena with respect to stream loadings and oxygen requirements:

1. Sludge deposits may decompose anaerobically even though aerobic conditions exist in the water above. The escaping gases may cause incompletely oxidized products of anaerobic decomposition to go into suspension, resulting in a higher B.O.D. of the liquid. Also the gases themselves and other soluble organic matter may go into solution and increase the B.O.D.
2. A reservoir and dam act as a settling basin and aerating device respectively.
3. Suspended matter settles out in the stream at lower flows. At higher flows much suspended matter is retained; in addition, material previously deposited is dislodged and carried downstream.

The following table gives the monthly averages of B.O.D. in pounds per day at all stations between Grand Forks and the International Boundary.

POUNDS OF 20° — 5-DAY B.O.D. AT STATIONS BELOW GRAND FORKS

Mo.	1938 Nov.	Dec.	1939 Jan.	Feb.	Mar.	Apr.	May	June	Aug.	Sept.	Oct.	Nov.	Dec.
Sta.													
5	10157	9302	6853	4385	7500	87890	13865	8595	2548	4120	13707	22810	20368
4	12442	9574	10852	2401	5045	104420	16947	9772	3055	4330	11508	16878	26169
3	5511	9936	9579	2493	3674	115506	20365	9575	1555	2799	4830	9739	9934
2	2579	9149	9564	2657	2446	118201	20218	5148	2713	3091	4186	10098	7217
1	2683	7568	9730	2203	2387	137489	19753	5930	3858	2608	3833	5023	4447

One significant fact that can be observed from the above tabulation is that the open water months of high pollution, except for spring runoff, show a progressive decrease in B.O.D. from Station 4 to Station 1 and the months of ice coverage, Dec. 1938, Jan. and Feb. 1939, show no significant change in B.O.D.

OXYGEN REQUIREMENTS UNDER ICE COVERAGE

In order to present a picture of the oxygen balance in the stream under existing ice coverage conditions, the oxygen required and the oxygen available have been computed for each station by months. (See tables XXIII and XXIV.) A summary of the 1938-39 winter critical season oxygen relationships at stations 6, 5, 4, 3, 2, and 1 has also been prepared and included in these tables. The net daily oxygen surplus or deficit in pounds for each station is shown in the tables. Oxygen requirement computations cover only the amount of oxygen that would be utilized by the biochemical stabilization of the wastes in the stream and do not take into account the surplus of oxygen required for the maintenance of fish life and the maintenance of other essential standards of stream sanitation.

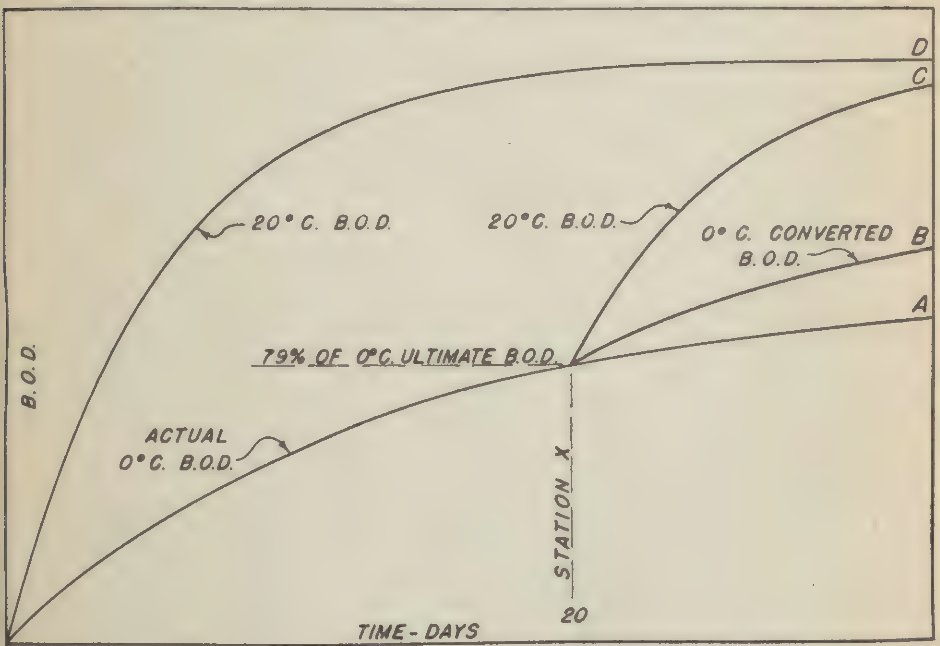
Calculations are based on observed stream flow, observed dissolved oxygen and 5-day 20°C. B.O.D. Lake Winnipeg has been taken as the point of final disposal of all wastes. However, for each station between Fargo and Grand Forks, the oxygen requirement has been computed for an incubation period equal to the time of flow from the station to Grand Forks. This procedure was followed because aeration, dilution and pollution at Grand Forks change the oxygen relationships entirely. For each station below Grand Forks the oxygen requirement is computed for an incubation period equal to the time of flow to Lake Winnipeg. In Tables XXIII and XXIV only the oxygen requirement in pounds daily under ice coverage has been calculated.

Oxygen requirements during ice coverage in terms of stream flow and for existing conditions are shown in Tables XXV and XXVI. Under ice coverage no pollution of significance is discharged into the river except at Fargo and Grand Forks. If there were no disturbing influences, the stream flow necessary between Fargo and Grand Forks (to be supplied at Fargo) could be calculated on the basis of the observed stream loading at Fargo. Similarly, the flow to be supplied at Grand Forks could be calculated on the basis of the observed stream loading at Grand Forks. In computing stream flows required under existing ice coverage conditions the effect of such influences as sedimentation, scouring of sludge, and solution of sludge and sludge digestion products made necessary a slightly different procedure.

This procedure consisted of calculating, for example, for the stations from Fargo to Grand Forks, the oxygen requirement from Fargo to each station and from each station to Grand Forks. The largest oxygen requirement was considered the determining one. Stream flows required on the basis of one, two, three, and four p.p.m. available oxygen are shown in the tables. Additional data on stream flow requirements are contained in Appendix IV. These data include minimum required stream flows during both ice coverage and

open water conditions with existing treatment and with 85 per cent treatment of all wastes.

The method of converting 5-day 20°C. B.O.D.'s to 0°C. B.O.D.'s is outlined in Appendix III. It is recognized that the method is somewhat arbitrary. In converting 5-day 20°C. B.O.D.'s to 0°C. B.O.D.'s the method used is basically accurate only at the point of discharge of wastes. It is known that the ultimate first stage B.O.D. at 20°C. is higher than the ultimate first stage B.O.D. at 0°C. In other words, some organic matter that will not be oxidized at 0°C. is oxidized at 20°C. For example, at a Station X 20 days in time of flow below the point of discharge of wastes, 79 per cent of the first stage 0°C. B.O.D. of the wastes discharged will be satisfied. (See Conversion Table in Appendix III.) The ultimate first stage 20°C. B. O. D. of a sample taken at Station X, however, will be in excess of the 21 per cent remaining to be satisfied at 0°C. It is not strictly correct, therefore, to say that the first stage 0°C. B.O.D. for any specific period of incubation at this Station X is the same percentage of the 5-day 20°C. B.O.D. that it would be for the same period of incubation at the point of discharge of wastes.



In the above graph 21 per cent of the ultimate first stage 0°C. B.O.D. remains to be oxidized at the end of 20 days. A sample taken at Station X should give a continuation of the lower curve (A) if incubated at 0°C. However, 20°C. incubations were actually

made resulting in the oxidation of substances not acted upon at 0°C. (Curve C.) Converting the 20°C. results to 0°C. gives a curve (B) which is greater than an actual 0°C. incubation would have given.

The method as employed, while theoretically not entirely correct, appeared to be a practical approach to the problem. The oxygen requirements obtained by this method would tend to be slightly higher than required rather than lower.

SUMMARY

Under ice coverage the dissolved oxygen content depleted to zero in from two to six weeks in the Red River as well as in some of its tributaries. Exceptions to this were stations located immediately below dams or stretches of open water. The effect of aeration resulting from a dam was noticed continuously throughout the winter season at Station 5, located 12 miles below the Riverside Park (Grand Forks) Dam. At no time was a zero dissolved oxygen content recorded at this station despite the fact that during October, November, and December strong sugar refinery wastes were being discharged a short distance above the dam. However, at Station 4, located 25 miles below this dam, zero dissolved oxygen conditions were found three weeks after ice coverage.

A series of dams in the Fargo area and the open stretch of water below the Fargo sewage treatment plant outfall provided oxygen at Station 11 during the entire winter season. At Station 10, located 25 miles below Station 11, the effect of aeration was still observed; zero dissolved oxygen conditions were not found until six weeks after ice coverage.

The dissolved oxygen was depleted more rapidly below Grand Forks because of the greater stream loading. In addition to the 2437 pounds of B.O.D. from other industrial and municipal wastes at Grand Forks, approximately 24,000 pounds of B.O.D. were contributed daily by the beet sugar plant during its period of operation. About 1400 pounds of B.O.D. per day were contributed by Fargo and Moorhead. The stream flow at Grand Forks was not more than three or four times that at Fargo on an average.

In order to maintain a satisfactory condition in the river, it is necessary that the oxygen content shall at no time be entirely depleted. It is assumed that in order to sustain fish life the dissolved oxygen should be approximately three parts per million minimum. With a dissolved oxygen content of six p.p.m. below the dam at Grand Forks there would be three p.p.m. available to oxidize the treated sewage and other wastes. With a flow of 200 c.f.s. the resulting available oxygen would be 3240 pounds per day. The 24,000 pounds of B.O.D. mentioned above as contributed daily from the beet sugar plant is the 5-day 20°C. value, which approximates the 30-day 0°C. B.O.D. The 3240 pounds of available oxygen is obviously inadequate and would be utilized in approximately two days at 0°C.

(See Conversion Table, page 122.) In order to provide sufficient oxygen to accommodate the 0°C. demand to Lake Winnipeg, the flow would have to be seven or eight times the 200 c.f.s. mentioned above or approximately 1500 c.f.s. and this does not take into consideration the daily load of about 2400 pounds of B.O.D. from other industrial and municipal wastes discharged at Grand Forks. From these calculations the need for additional treatment is obvious, since providing supplemental flows of this magnitude is not economically feasible.

In general, higher flows were attended by less objectionable conditions than lower flows. Higher flows, in addition to providing greater dilution, result in higher velocities, thereby carrying the demand farther downstream in a shorter length of time. (Unfortunately, below Grand Forks the critical fall and winter conditions of low flow are coincident with the operation of the beet sugar plant.)

Determination of the re-aeration provided by dams was not included as a regular sampling procedure. However, sufficient samples were collected and data obtained to indicate that low temperature oxygen-deficient waters would contain at least 6 p.p.m. dissolved oxygen after passing over a dam of the type most commonly encountered in the River. The information obtained was for flows up to approximately 200 c.f.s. Normally, high flows do not occur during winter critical periods and it would be only during a time of relatively complete submergence of the dam that a total oxygen content of 6 p.p.m. could not be obtained.

In order to regulate the flow in the Red River from within the Basin, water must be stored in lakes, reservoirs, or river channels. It is known that the oxygen content of water in shallow lakes (less than 20-30 feet) may, due to natural pollution alone, be depleted seriously, and even completely, during ice coverage.[1] As the period of ice coverage increases the oxygen depletion becomes greater. Also, water stored in artificial reservoirs has been observed to be devoid of oxygen, during ice coverage, due to natural pollution (See Appendix V). If such impounded waters are to be used for the dilution and oxidation of sewage and other wastes, the quantity of water necessary will depend on the oxygen content of such water. Therefore, to be of greatest value for dilution and oxidation of wastes, such waters should be aerated upon release from storage reservoirs. A low overflow or spilling dam, designed for this purpose, could accomplish aeration to the extent of increasing the dissolved oxygen content to at least 6. parts per million. This statement is based on actual observations at low overflow dams in the Red River.

The suitability of relatively unpolluted streams for dilution purposes was investigated during the course of the study. A detailed

[1] Regional Planning. Part V—Red River of the North, 1937, National Resources Committee.

discussion of the findings is contained in Appendix V. From the data collected it has been concluded that the biochemical oxygen demand of surface runoff, bottom sediment and decaying vegetation is generally sufficient to cause serious oxygen depletion. With the exception of the Missouri River, none of the streams studied were found to be of appreciable value as sources of oxygen—containing dilution water during the critical winter period. In most cases these tributaries would be of value if they were aerated just prior to their confluence with the Red River. The dissolved oxygen content of the Missouri River did not fall below 9.8 p.p.m. during the winter of 1938-39.

In a sluggish stream such as the Red River, the formation of sludge deposits is likely to occur wherever raw or partially treated wastes are discharged. Extensive sludge deposits were observed in and below Grand Forks. As pointed out under "Stream Loadings", higher flows apparently dislodge large quantities of accumulated sludge from behind dams and from other sections of the River below points of pollution. The progressive increase in B.O.D. from Grand Forks to the International Boundary as observed in the February 1938 study indicates the presence of oxygen-requiring sludge deposits throughout this entire stretch of river. From this it would appear that sludge deposits may be picked up, carried downstream and redeposited, at least in part.

Large variations in stream loadings may occur because of sludge deposits. As pointed out previously in this report, the difference in stream loading between two stations may be greater or less than the pollution loading discharged into the River between these two stations depending on whether settling or scouring is taking place. When neither settling nor scouring is taking place, the B.O.D. of the stream may be increased as it flows over sludge deposits. Direct solution of deposited organic matter and of oxygen-requiring decomposition products of sludge digestion, as well as entrainment of organic particles floated by gas evolved during sludge digestion, may be responsible for an increase in the B.O.D. of the stream. This phenomena is evident especially during ice coverage.

The determination of required stream flows under open water conditions is complicated both by sludge deposits and algal activity. Since the exact effect of these two influences cannot practically be determined, and since they tend to offset each other, they have not been taken into consideration in calculating minimum required stream flows. With effective treatment of all wastes the effect of sludge deposits should be of diminishing importance. Algal activity is extremely variable and more or less unpredictable. Dissolved oxygen supersaturation to the extent of 60 per cent has been observed in the Red River. Channel clearance and the elimination of marshy and heavily vegetated areas should tend to decrease the importance of algae in relation to oxygen balance in the stream since such areas favor the growth of many micro-organisms in-

cluding algae. It would be expected that other taste and odor producing organisms also would be less abundant as a result of channel clearance.

Industrial waste discharges into the Red River were of significant importance in this investigation. It was necessary to study the processes from which the wastes result, and to determine the quantity, characteristics, and behavior of the wastes. This phase of the study was almost entirely of a strict research nature since little of the necessary type of information was available prior to this study. Long range incubations of waste samples and river samples containing the wastes were carried out at 0°C. and 20°C.

The research information obtained indicates that the rate and extent of oxygen utilization by industrial wastes is dependent on several factors including nature of the waste, temperature, extent of dilution and type of dilution water. It has long been known that the rate of oxygen utilization becomes less as the temperature is lowered, but the definite rate of use at specific temperatures, including 0°C., had to be determined for each waste and for specific mixtures of wastes and river water. Results indicated that these rates of oxygen use were not the same as the rates generally accepted for domestic sewage dilutions and that a mixture of domestic sewage, wastes and river water did not react at the same rate as domestic sewage dilutions.

At temperatures near 0°C. the mixture reacted at a slower rate than that generally accepted for sewage dilutions. On the basis of limited data, the mixture is believed to react at a faster rate than generally accepted for sewage dilution during summer months at temperatures near 20°C. The rate and extent of oxygen use by samples of wastes diluted with synthetic dilution waters was found to be affected profoundly by the nature of the dilution water and the extent of dilution. Samples of wastes diluted with river water did not react the same as samples diluted with prepared (synthetic) dilution waters. Samples of mixed wastes and river water did not react the same as dilutions of the waste preponderant in the mixture of wastes and river water. The difference in behavior was of varying magnitude. It is essential to determine, therefore, not only the basic behavior of each industrial waste separately but also in combination with other wastes under specific stream conditions. Since the behavior of an industrial waste may be quite different than that of domestic sewage, it is not correct to forecast the effect of industrial wastes on the basis of the behavior of domestic sewage.

A detailed presentation of the research data on industrial wastes and domestic sewage has not been made in this report. A separate report on this phase is contemplated by the North Dakota State Department of Health.

The use of raw Red River water or ice for household purposes, except after boiling, must be considered dangerous from a public health standpoint. In general, no surface water should be used

for drinking and similar purposes unless properly treated. Heavy sewage pollution in the Red River makes the use of this water untreated a very hazardous procedure. Some danger to public health arises also out of the use of the River for swimming, boating, and fishing.

Improvements in the condition of the River can be brought about by sewage and waste treatment, increased stream flow, aeration, and channel clearance. All of the important wastes discharged into the River are considered amenable to effective treatment. Some regulation of flow may be provided within the basin; supplemental flows may be provided from other watersheds. Overflow or spillway dams, designed as aerating devices appear to be a practical means of replenishing the oxygen content of oxygen deficient waters, and may be used in the main stream, at the outlet to natural and artificial reservoirs, or on tributaries or diversion channels just prior to their confluence with the main stream; any combination of these also may be used.

The practice by individuals and villages of dumping garbage, rubbish, potatoes, manure, and the like on the ice during winter months should be prevented. Much of this material, instead of being carried to the mouth of the River, merely settles to the bottom and exerts an additional oxygen demand on the River. Barnyard drainage should be so diverted that it will not discharge directly into the River.

In working out a corrective program, the cost of providing desired treatment must be balanced against the cost of constructing and operating storage, aerating and diversion works. Public convenience must be balanced against reasonable standards of stream sanitation. The entire corrective program should be a coordinated composite of solutions to the individual problems.

TABLES

AND

FIGURES

BIOLOGICAL DATA—PLANKTON

	Sta. No. 1 Pembina Composite	Sta. No. 2 Drayton Composite	Sta. No. 3 Grafton Composite	Sta. No. 4 Oslo Minn. Side	Sta. No. 4 Oslo N.D. Side	Sta. No. 6 G. Fks. Composite	Sta. No. 7 G. Fks. Composite
Blue-Green Algae							
Oscillatoria geminata			2,592	15,480	6,120	16,200	7,920
Merismopedia tenuissima		1,440					
Subtotal		1,440	2,592	15,480	6,120	16,200	7,920
Green Algae							
Scenedesmus dimorphus			288				
Scenedesmus sp.			288	360	360	1,080	1,080
Subtotal			576	360	360	1,080	1,080
Diatoms							
Centronella Reichelti		360					
Cocconeis placentula		2,880	1,440				
Cyclotella sp.	13,536	13,680	7,776	18,000	4,680	418,300	39,960
Cymatopleura solea	7,488	3,960	3,744				
Diatoma vulgare		1,080			360		
Diatoma sp.						720	360
Gomphonema acuminatum	1,728	720			360	1,800	
Gyrosigma sp.	864	360					
Melosira granulata			288				720
Melosira Roeseana					50		
Navicula spp.	3,456	1,440	1,152	720	6,120	3,240	4,680
Surirella Ovata	2,592	720					
Synedra tenuissima	288	1,080		1,080	360	2,160	9,000
Synedra ulna	2,016	1,440		1,440		2,160	7,200
Subtotal	31,968	27,720	14,400	21,240	11,930	428,380	61,920
Protozoa							
Amphileptus anser	2,304			360			
Chlamydomonas sp.	576	360	576			720	1,800
Ciliata		38	120		1,675	50	
Colpidium sp.				360			
Euglena sp.	864					360	
Vorticella sp.				3,240			
Subtotal	3,744	398	700	3,960	1,675	1,130	1,800
Miscellaneous							
Nematode						360	
Immature Copepods						50	
TOTAL	35,700	29,560	18,260	41,040	20,085	447,200	72,720

RED RIVER SURVEY—1939
Table I—1

BIOLOGICAL DATA—PLANKTON

	Sta. H Red. L.R. Composite	Sta. 8 Climax Composite	Sta. 9 Halstad Composite	Sta. 10 Georgetown	Sta. 11 Moorhead Composite	Sta. 12 Moorhead Ab. Intake	Sta. 12 Moorhead Below In.
Blue-Green Algae							
Oscillatoria geminata		2,160	9,720	69,480	67,935		6,840
Coelosphaerium sp.					647		
Merismopedia tenuissima	2,880						
Subtotal	2,880	2,160	9,720	69,480	68,582		6,840
Green Algae							
Arthrodesmus sp.				720			
Closterium moniliferum			Present	Present			
Scenedesmus dimorphus		360					
Scenedesmus sp.	2,880				647		720
Subtotal	2,880	360		720	647		720
Diatoms							
Asterionella gracillima			374	720		360	
Cocconeis placentula	720		13,500				360
Cyclotella sp.	18,720	12,600	17,950	19,080	29,115	8,640	51,120
Cymatopleura solea	360			1,080	23,292		
Cymbella sp.				360			
Diatoma vulgare	1,440		374		1,294	360	360
Diatoma sp.					1,941		360
Gomphonema acuminatum		1,080			4,529	360	50
Gyrosigma sp.		360	2,244				
Homoeocladia sigmoidea		360		1,080			
Melosira granulata		2,880		4,320	4,529	1,800	
Melosira Roescana			374	720	1,294		3,600
Navicula spp.	5,760	10,800	4,488	26,640	23,292		5,760
Surirella ovata			748				
Surirella ovalis		360		1,800	1,941		
Synedra tenuissima	720	27,000	13,090	1,080	647		2,880
Synedra ulna		10,440	43,760	36,720	12,940	1,800	7,760
Subtotal	27,720	65,880	96,900	93,600	104,800	13,320	70,250

Continued on next page

RED RIVER SURVEY—1939
Table I—2

BIOLOGICAL DATA—PLANKTON (Continued)

	Sta. H Red L. R. Composite	Sta. 8 Climax Composite	Sta. 9 Halstad Composite	Sta. 10 Georgetown	Sta. 11 Moorhead Composite	Sta. 12 Moorhead Above In.	Sta. 12 Moorhead Below In.
Rotifers							
Diurella porcellus		50					
Keratella quadrata							50
Rotifer sp.				25	647		
Subtotal		50		25	647		50
Protozoa							
Epistylis sp.				113			
Amphileptus anser		360	374			2,160	720
Chlamydomonas sp.	360	360	2,620		647		
Ciliata	4,320			138	743		
Euglena sp.	360		1,122	25			
Frontonia sp.		50					
Vorticella sp.		150	748	850	1,290	720	150
Phacus sp.				38			
Subtotal	5,040	920	4,860	1,164	2,680	2,880	870
Miscellaneous							
Nematode					647		
Immature Copepods					23		
TOTAL	38,520	69,370	111,500	165,000	178,044	16,200	78,730

RED RIVER SURVEY—1939
Table I—3

BIOLOGICAL DATA—BOTTOM FAUNA
Composite Tabulation

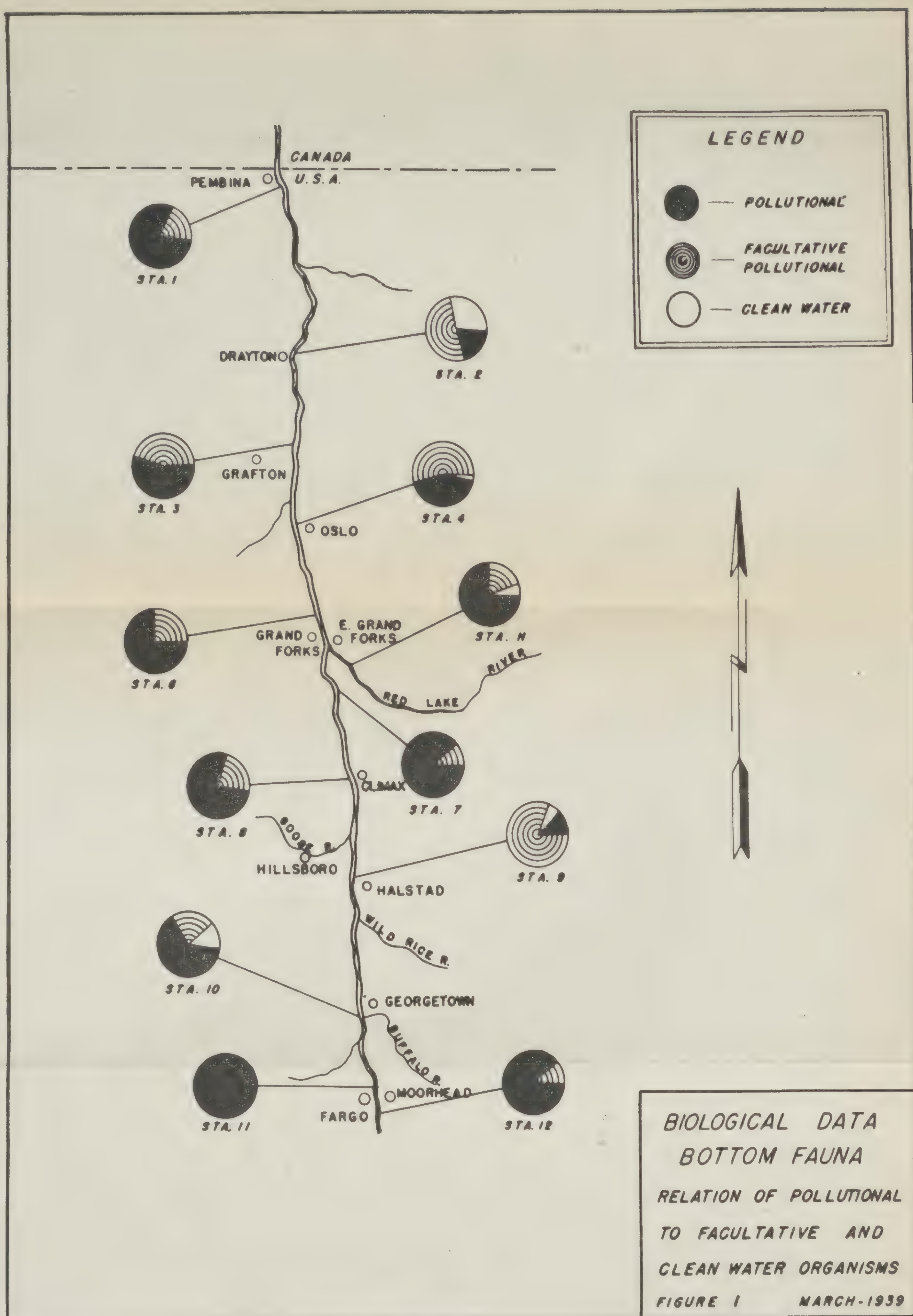
	Average number of organisms per sq. yd. (Divide all by 2)						
	Sta. 1 Pembina	Sta. 2 Drayton	Sta. 3 Grafton	Sta. 4 Oslo	Sta. 6 Gr. Fks.	Sta. 7 Gr. Fks.	Sta. H Gr. Fks.
Nemathelminthes							
Nematoda			12				
Annelida							
Oligochaeta							
Limnodrilus sp.	400	6	129	293	235	1,527	1,463
Tubifex sp.				205			35
Naididae		6		35		517	94
Hirudinea							
Erpobdella punctata	6	17	18	29			
Mollusca							
Sphaerium sp.			120	59		6	
Arthropoda							
Crustacea							
Hyalella knickerbockeri		30	24				
Insecta							
Diptera							
Chironomus decorus				6		399	12
" tentans							64
" sp. No. 1				6			
" sp. No. 8		70					
Diamesa fulva				59			
Procladius culiciformis	17			70		59	247
Pentaneura carnea	59	106		458			
Orthocladius nivoriunda		42					
Chaoborus punctipennis					65	200	41
Palpomyia sp.	24	6	24	47	12	23	29
Ephemeroptera							
Ephoron sp.							141
Mayfly—dead, disintegrated				6			
Miscellaneous Insecta							
Polycentropidae		17					
Corixa sp.			6				6
TOTAL	506	300	333	1,273	312	2,732	2,138

RED RIVER OF THE NORTH
March 1939. Table II—1

BIOLOGICAL DATA—BOTTOM FAUNA
Composite Tabulation

	Average number of organisms per sq. yd. (Divide all by 2)				
	Sta. 8 Climax	Sta. 9 Halstad	Sta. 10 Georgetown	Sta. 11 Moorhead	Sta. 12 Moorhead
Nemathelminthes					
Nematoda					
Annelida					
Oligochaeta					
Limnodrilus sp.	53	76	382	22,472	523
Naididae	12		217	1,093	88
Nirodinea					
Erpobdella punctata		6	6		
Glossiphonia nepheloidea			6		
Mollusca					
Amnicola sp.			6		
Kampsilis siliquoidea					
Sphaerium sp.			12		
Arthropoda					
Crustacea					
Hyalella knickerbockeri		29			
Cambarus sp.					
Insecta					
Diptera					
Chironomus digitatus			12		
" plumosus					587
" tentans				6	
" sp. No. 1					
Diamesa fulva	6	53	6		
Procladius culiciformis		6			100
Pentaneura carnea	12	76			
Orthocladius nivoriunda				370	
Spaniotoma sp. F.			6		
TOTAL	83	246	653	23,941	1,298

RED RIVER OF THE NORTH
March 1939 Table II—2



BIOLOGICAL DATA
BOTTOM FAUNA

RELATION OF POLLUTIONAL TO FACULTATIVE AND CLEAN WATER ORGANISMS

FIGURE 1 MARCH-1939

BIOLOGICAL DATA—BOTTOM FAUNA
Composite Tabulation

	Average number of organisms per sq. yd. (Divide all by 2)				
	Sta. 8 Climax	Sta. 9 Halstad	Sta. 10 Georgetown	Sta. 11 Moorhead	Sta. 12 Moorhead
Insecta					
Diptera					
Tanytarsus dives					17
Tanypus sp. A (Mallech)		17	17		
Psychoda sp. A				53	
" sp. B				17	
" sp. Pupae				29	
Chaoborus punctipenn					35
Palpomyia sp.		676	117		
Telmatoscopus albipunctatus				6	
Ephemoroptera					
Hexagenia sp.			6		
Ephoron sp.			82		
Caenis sp.		18			
Miscellaneous Insecta					
Polycentropidae		18			
Hydropsyche sp.			6		
Corixa sp.			41		6
Haliplidae		12			
Oomphus		6	6		
TOTAL		747	275	105	58

RED RIVER OF THE NORTH
March 1939 Table II—3

BIOLOGICAL DATA—BOTTOM FAUNA
Summary and Classification as Index Organisms

Location of Samples		Pollutional Forms		Facultative Pollutional Forms		Clean-Water Forms		Total Number per sq. yard	Number of Species
		Average No/sq/yd	Percent of total	Average No/sq/yd	Percent of total	Average No/sq/yd	Percent of total		
Pembina	Sta. 1	406	80.2	100	19.8	...	0.0	506	5
Drayton	Sta. 2	59	19.6	153	51.1	88	29.3	300	9
Grafton	Sta. 3	182	54.8	150	45.2	...	0.0	332	7
Oslo	Sta. 4	570	44.7	700	54.8	6	0.5	1,276	12
Grand Forks	Sta. 6	235	75.3	77	24.7	...	0.0	312	3
Grand Forks	Sta. 7	2,444	89.4	288	10.6	...	0.0	2,732	7
Grand Forks	Sta. H (Trib.)	1,610	75.2	388	18.2	141	6.6	2,139	11
Climax	Sta. 8	65	78.3	18	21.7	...	0.0	83	4
Halstad	Sta. 9	112	11.3	829	83.3	54	5.4	995	12
Georgetown	Sta. 10	611	65.8	206	22.1	112	12.1	929	16
Moorhead	Sta. 11	23,671	98.4	376	1.6	...	0.0	24,047	7
Moorhead	Sta. 12	1,198	88.3	159	11.7	...	0.0	1,357	7

RED RIVER OF THE NORTH
March 16-22, 1939 Table III—1

DISSOLVED OXYGEN—MONTHLY AVERAGES—P.P.M.
Table IV

Station	12	11	10	9	8	7	6	5	4	3	2	1
1938												
Nov.	12	9.3	10.7	11.36	12.96	13.2	10.95	6.11	4.11	7.3	9.1	12.66
Dec.	9.2	6.5	1.7	2.2	2.4	9.9	7.9	3.4	.2	0.0	0.0	.4
1939												
Jan.	8.9	8.7	4.2	1.9	.5	1.1	3.7	2.9	1.5	.7	0.0	0.0
Feb.	10.4	9.8	6.7	3.3	1.7	.9	2.5	3.8	2.6	.8	.7	0.0
Mar.	9.7	9.8	6.8	4.1	2.8	1.1	2.1	5.0	3.3	1.4	1.1	1.1
Apr.	11.5	11.2	11.2	11.2	10.8	10.1	9.5	10.5	10.0	9.0	9.0	9.1
May	8.4	8.6	8.3	10.1	8.8	8.3	7.3	7.6	7.7	9.8	9.7	9.2
June	7.8	7.7	8.0	8.3	7.9	6.0	5.0	5.6	5.4	8.8	9.0	8.0
Aug.	8.8	4.9	10.2	6.2	7.5	6.5	5.5	3.1	6.1	8.0	7.3	8.6
Sept.	6.5	2.5	9.4	8.6	8.2	7.6	6.7	5.6	7.1	7.8	7.9	8.8
Oct.	8.6	8.4	8.6	10.5	10.2	8.6	9.0	6.5	6.7	10.5	11.2	11.0
Nov.	12.8	8.8	12.0	15.0	15.3	10.9	11.5	9.5	9.0	11.0	11.8	12.2
Dec.	12.6	8.8	9.3	15.1	15.5	19.9	11.5	7.3	4.5	3.3	5.5	9.6
1940												
Jan.	9.2	3.2	.9	3.7	5.6	18.6	10.1	7.3	1.9	.3	.3	1.2
Feb.	5.3	2.6	0.0	0.0	0.0	12.0	6.75	6.8	4.5	.85	1.1	.2
Mar.	....	1.14	0.0	0.0	...	...	....	...	5.4	...	1.2	.6

DISSOLVED OXYGEN—MONTHLY AVERAGES—P.P.M.
Table V

Station	A	B	C	D	E	F	H	I	J	K	L
1938											
Nov.	...	3.1	...	6.5	4.9	...	12.5	...	11.6	9.1	11.4
Dec.	...	.1	...	.1	.1	...	7.6	...	7.0	.3	7.6
1939											
Jan.	...	0	...	0	0	...	2.9	...	2.1	0	5.3
Feb.	...	0	...	0	0	...	1.3	...	1.7	0	3.7
Mar.	...	1.5	...	.7	.9	...	1.2	...	3.2	1.4	4.0
Apr.	10.4	8.3	10.6	7.9	8.8	15.3	8.5	12.7	11.5	11.1	10.7
May	7.5	8.8	8.9	10.3	8.5	9.4	7.1	9.2	8.4	8.7	9.0
June	5.9	6.4	...	8.7	8.8	...	6.8	7.6	7.7	7.3	8.2
Aug.	6.7	8.8	...	7.5	10.4	...	7.3	...	7.5	7.9	6.9
Sept.	...	8.7	...	8.6	8.3	...	8.1	...	7.3	7.5	6.6
Oct.	...	9.8	...	10.5	8.0	10.0	9.7	...	8.3	6.7	8.2
Nov.	...	...	...	...	...	11.4	12.7	...	11.8	11.0	11.6
Dec.	...	...	...	...	...	...	11.4	...	8.7	8.4	11.4
1940											
Jan.	...	...	...	...	...	...	8.9	...	4.4	...	...
Feb.	...	...	...	...	...	...	5.2	...	...	...	...
Mar.	...	...	...	...	...	...	4.7	...	...	...	...

DISSOLVED OXYGEN MONTHLY AVERAGES—PER CENT SATURATION
Table VI

Station	12	11	10	9	8	7	6	5	4	3	2	1
1938												
Nov.	91.	72.8	78.1	83.4	93	94.9	80.8	45	29.7	51.5	63.8	88.2
Dec.	64	46.2	11.6	15.0	16.4	67.7	54.	23.2	1.4	0.0	0.0	2.7
1939												
Jan.	60.8	60.4	28.7	13.0	3.4	7.52	25.3	19.8	10.3	4.8	0.0	0.0
Feb.	71.	67.	45.8	22.6	11.6	6.17	17.1	26.0	17.8	5.5	4.8	0.0
Mar.	66.3	67.	46.6	28.1	19.2	7.5	14.4	34.2	22.6	9.6	7.5	7.5
Apr.	88.	85.3	84.	84.	81.	75.4	70.1	77.4	73.7	66.8	67.1	67.2
May	84.4	86.5	82.7	101.	88.	85.7	74.7	78.	78.7	97.6	95.5	90.0
June	87.4	85.6	87.3	91.8	87.4	67.4	56.1	62.8	60.6	98.7	100.1	86.4
Aug.	100.	54.5	111.	67.7	81.8	74.8	63.4	33.2	69.1	85.6	78.1	92.0
Sept.	72.6	27.3	96.5	88.3	84.2	79.6	68.1	57.1	71.3	78.4	79.4	89.4
Oct.	76.	74.1	72.9	88.9	86.4	70.7	75.9	54.6	54.8	85.5	87.9	87.4
Nov.	91.8	66.3	86.2	107.4	109.6	78.6	83.6	67.6	64.6	76.2	81.7	86.2
Dec.	86.1	67.	63,6	103.0	106.	136.	78.6	49.9	30.8	22.6	37.6	65.7
1940												
Jan.	62.9	21.9	6.1	25.3	38.3	127.	69.0	49.9	13.	2.0	2.0	8.2
Feb.	36.2	17.8	0.0	0.0	0.0	82.1	46.2	46.5	30.8	5.8	7.5	1.4
Mar.	....	....	16.7	0.0	0.0	..	...	...	36.9	...	8.2	4.1

DISSOLVED OXYGEN—MONTHLY AVERAGES—PERCENT SATURATION
Table VII

Station	A	B	C	D	E	F	H	I	J	K	L
1938											
Nov.	....	21.8	....	46.3	34.4	....	87.8	....	81.4	65.7	82.7
Dec.	....	0.7	....	0.7	0.7	....	52.0	....	47.8	2.0	52.0
1939											
Jan.	....	0.0	....	0.0	0.0	....	19.8	....	14.4	0.0	36.2
Feb.	....	0.0	....	0.0	0.0	....	8.9	....	11.6	0.0	25.3
Mar.	....	21.9	....	4.8	6.2	....	8.2	....	21.9	9.6	27.3
Apr.	79.1	59.9	76.5	58.6	63.6	110.4	63.0	94.2	85.4	84.4	79.4
May	73.8	84.8	87.7	106.0	83.8	92.6	74.4	98.7	77.3	83.8	86.8
June	63.2	68.5	....	92.2	97.9	....	75.7	78.0	84.0	78.1	89.4
Aug.	74.5	92.2	....	78.6	120.0	....	84.1	....	78.6	84.4	75.2
Sept.	....	83.8	....	82.9	70.0	....	81.4	....	81.2	75.4	67.8
Oct.	....	78.6	....	81.9	67.4	84.2	79.7	....	83.5	57.0	69.1
Nov.	....	....	....	....	....	77.9	91.7	....	99.4	79.4	81.4
Dec.	....	....	....	....	....	....	77.9	....	62.8	57.4	82.3
1940											
Jan.	....	....	....	....	....	....	60.8	....	30.1	....	....
Feb.	....	....	....	....	....	....	35.5	....	....	....	....
Mar.	....	....	....	....	....	....	32.1	....	....	....	....

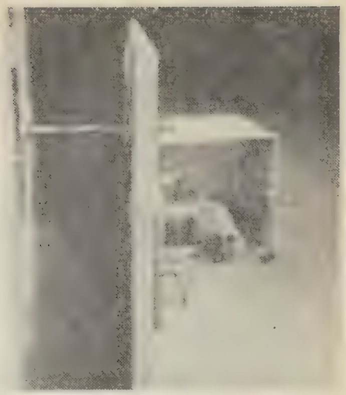
BIOCHEMICAL OXYGEN DEMAND—5-DAY, 20°C.
MONTHLY AVERAGES—P.P.M.
Table VIII

Station	12	11	10	9	8	7	6	5	4	3	2	1
1938												
Nov.	4.5	13.1	3.2	1.3	1.7	3.2	19.0	9.9	12.0	5.4	2.4	2.4
Dec.	3.3	12.3	1.6	1.7	1.4	2.7	17.3	8.7	9.0	9.2	8.6	7.7
1939												
Jan.	2.2	11.4	2.8	2.0	2.3	2.1	2.7	5.4	8.7	8.1	8.2	9.1
Feb.	1.7	4.8	3.7	1.8	1.4	1.3	2.3	3.5	1.9	1.9	2.0	1.6
Mar.	2.5	5.8	4.4	3.4	1.8	1.8	2.0	3.2	2.7	1.8	1.5	1.7
Apr.	4.5	5.2	5.5	5.5	6.2	5.0	6.1	5.2	6.1	6.2	5.9	6.9
May	2.5	4.6	2.7	3.4	3.4	2.7	3.1	2.8	3.3	3.8	3.6	3.1
June	4.2	5.7	5.1	3.6	3.3	2.8	2.2	2.3	2.6	2.6	1.4	1.7
Aug.	5.1	7.4	9.5	2.7	2.8	4.0	4.8	3.9	4.6	2.0	3.2	3.8
Sept.	4.8	13.7	6.6	3.2	3.7	3.9	3.7	3.5	3.8	2.4	2.7	2.1
Oct.	3.6	16.4	7.5	6.7	4.3	4.1	12.6	7.6	6.4	2.6	2.3	2.1
Nov.	4.2	15.4	3.7	5.1	10.1	3.2	20.4	12.8	9.5	5.4	5.5	3.8
Dec.	2.8	20.7	6.1	3.1	4.2	3.9	21.5	12.7	16.1	6.3	4.5	2.9
1940												
Jan.	3.3	26.0	7.5	7.7	6.4	3.0	17.5	9.5	6.9	8.4	7.8	4.0
Feb.	2.6	24.7	11.0	12.6	22.4	...	...	2.0	2.0	2.5	1.5	1.9
Mar.	....	....	13.2	12.0	21.3	...	...	...	4.2	...	1.2	1.7

BIOCHEMICAL OXYGEN DEMAND—5-DAY, 20°C
MONTHLY AVERAGES—P.P.M.
Table IX

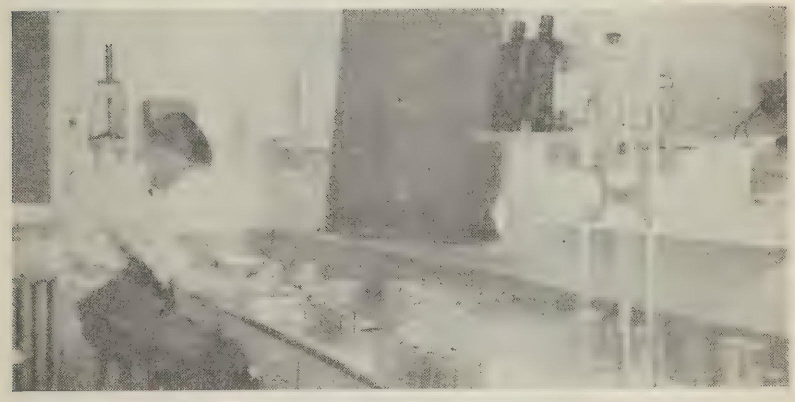
Station	A	B	C	D	E	F	G	H	I	J	K	L
1938												
Nov.	Dry	3.01	Dry	6.43	3.36	Dry	...	2.77	Dry	2.15	2.75	2.89
Dec.	Dry	6.25	Dry	9.60	4.90	Dry	...	1.82	Dry	1.00	1.00	1.58
1939												
Jan.	Dry	11.2	Dry	31.7	10.7	Dry	...	1.07	Dry	0.72	4.38	2.15
Feb.	Dry	Dry	Dry	Dry	21.35	Dry	...	1.35	Dry	1.80	4.72	3.08
Mar.	Dry	Dry	Dry	Dry	5.30	Dry	...	1.34	Dry	2.67	4.05	3.74
Apr.	3.80	4.21	4.59	3.78	4.55	7.18	...	2.11	4.64	2.86	4.11	5.88
May	1.64	2.92	6.25	9.46	4.50	5.27	...	3.43	5.64	1.41	1.73	3.25
June	1.50	1.70	Dry	10.51	5.73	Dry	...	3.25	5.35	1.59	1.54	4.86
Aug.	4.16	8.97	Dry	2.35	14.28	Dry	...	4.20	Dry	1.20	1.63	1.86
Sept.	....	6.62	Dry	22.26	8.65+	1.77	...	5.11	Dry	1.95	2.69	3.74
Oct.	....	6.08	....	8.84	6.00	3.32	...	4.64	....	4.63	6.71	5.47
Nov.	....	8.42	....	3.9	....	6.27	...	5.41	....	1.45	1.92	4.15
Dec.	....	....	....	....	....	5.22	...	1.66	....	1.58	1.25	2.42
1940												
Jan.	....	....	....	....	....	....	....	1.44	....	2.08	1.17	1.94
Feb.	....	....	....	....	....	....	...	....	....	1.73	....	....

Bismarck Laboratory



U. S. G. S. Wire Weight Gauge at Sta. 9

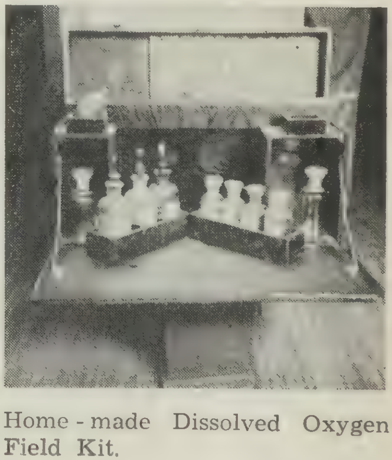
Water Bath Incubator—20° C.



Making Dissolved Oxygen Determinations in Grand Forks Laboratory

Figure 6

Sampling by Boat and Outboard Motor Below Grand Forks. Above and Lower Right.

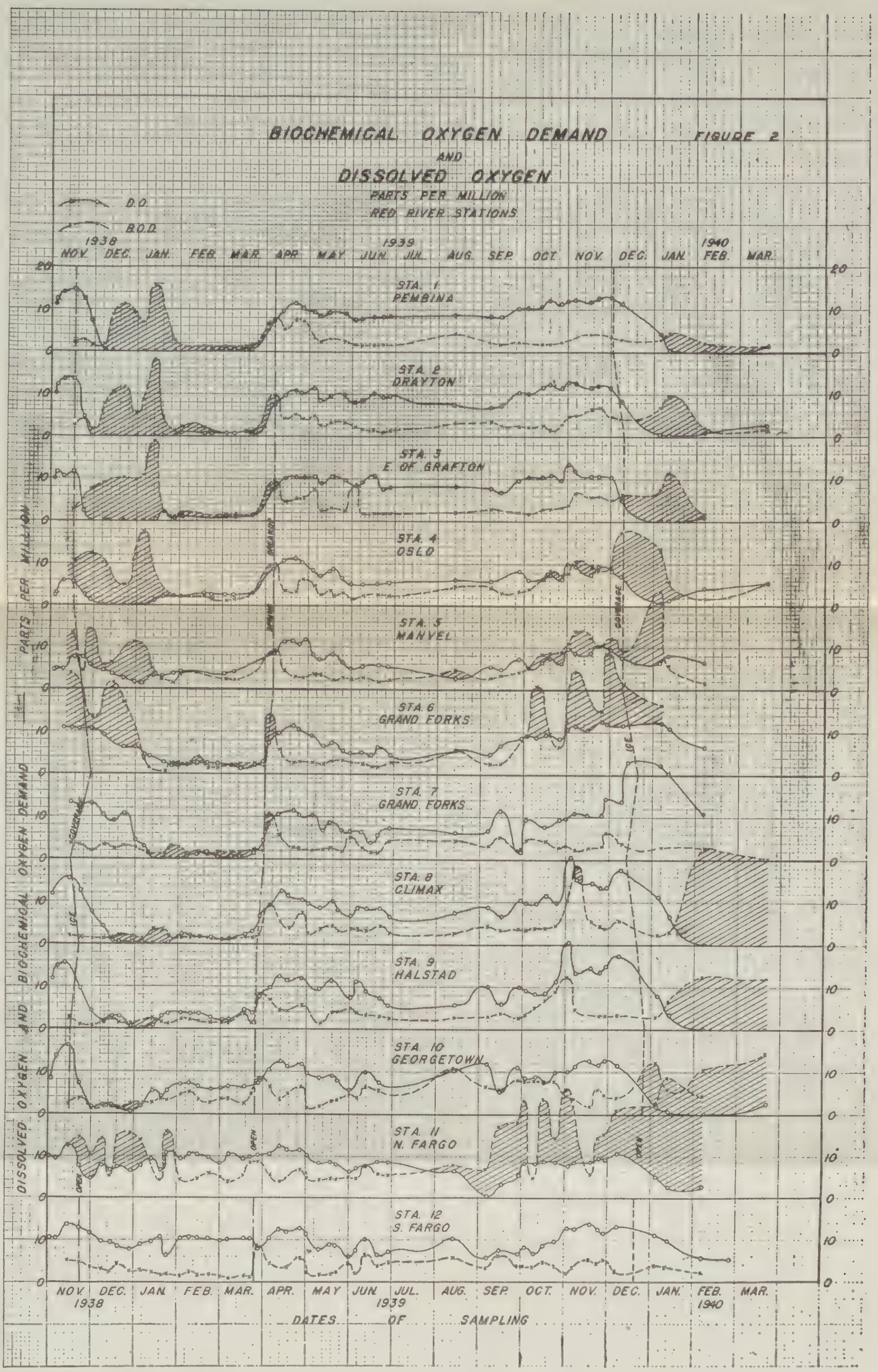


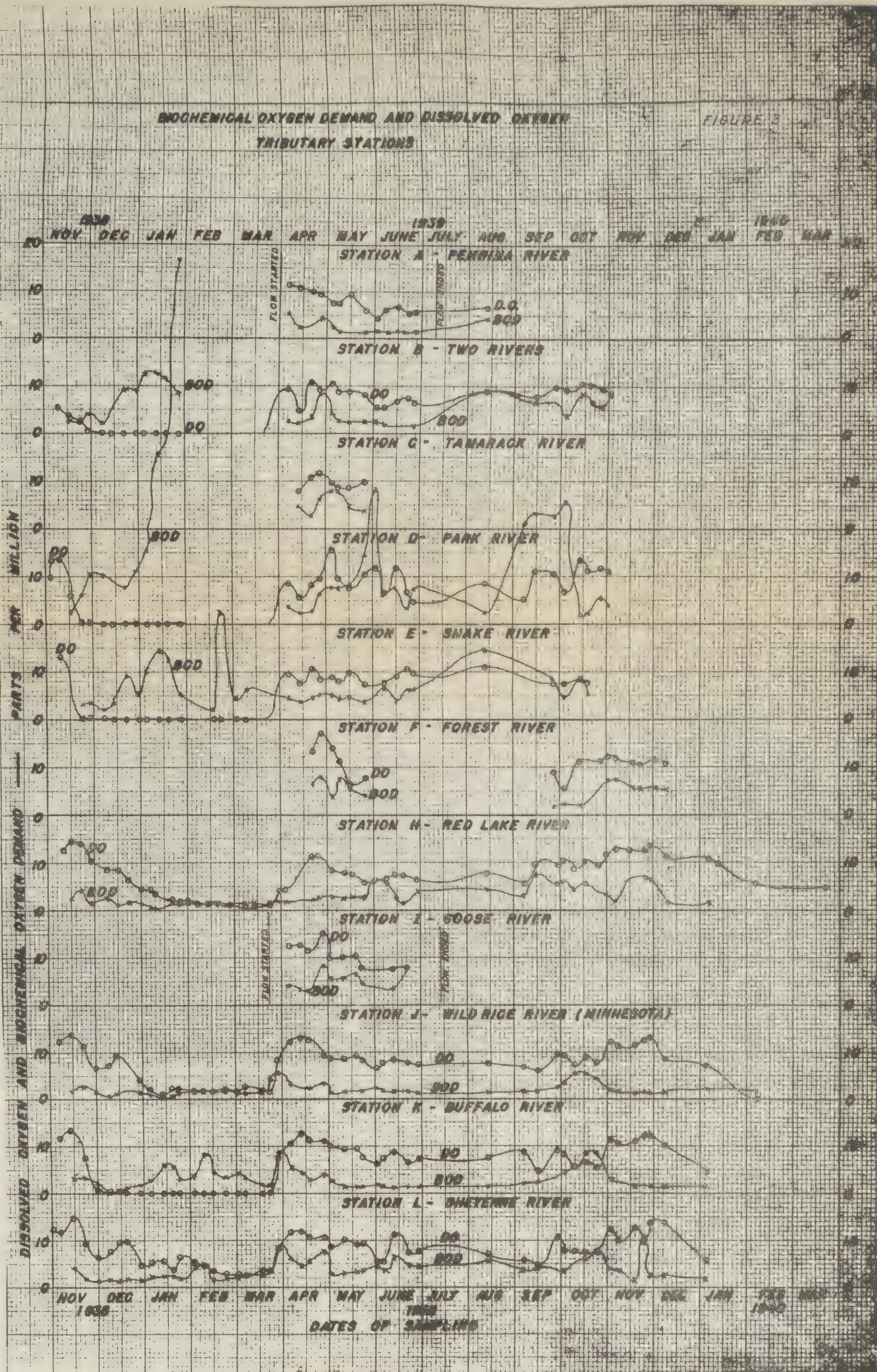
About to Lower Sampler From Bridge.

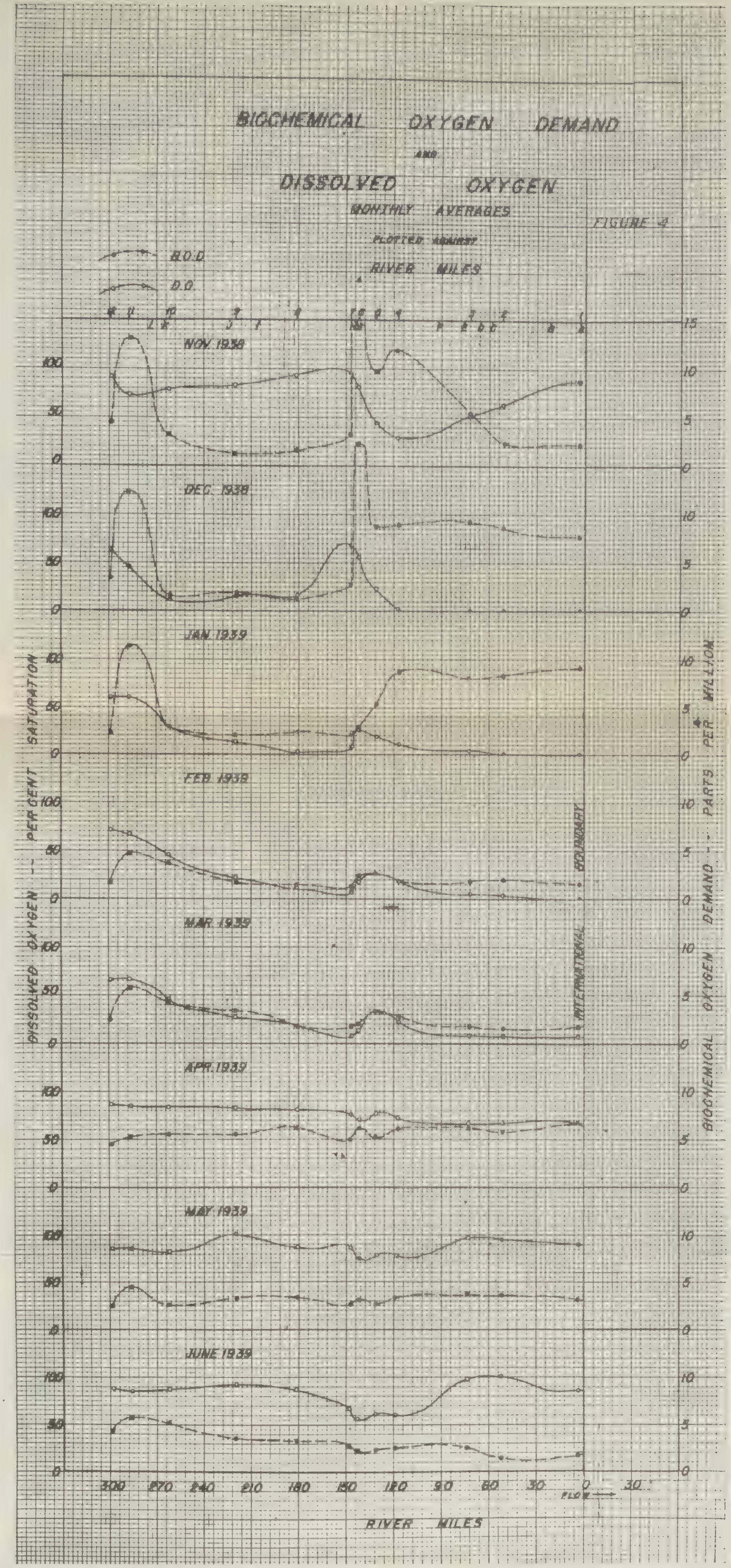
Home-made Dissolved Oxygen Field Kit.

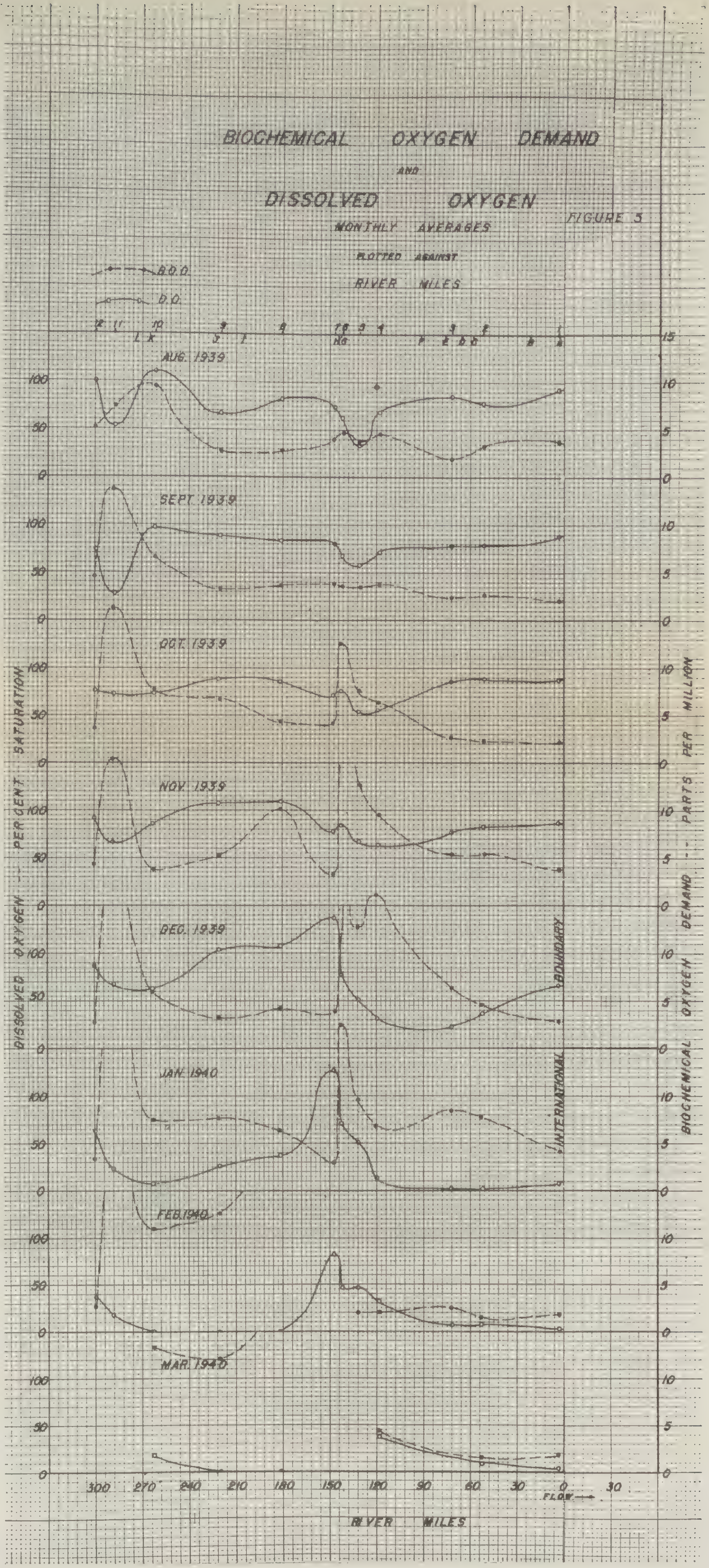
Figure 6

FIGURE 2


BIOCHEMICAL OXYGEN DEMAND
AND
DISSOLVED OXYGEN
PARTS PER MILLION
RED RIVER STATIONS
D.O.
B.O.D.
1938
1939
1940
NOV. DEC. JAN. FEB. MAR. APR. MAY JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR.
STA. 1 PEMBINA
STA. 2 DRAYTON
STA. 3 E. OF GRAFTON
STA. 4 OSLO
STA. 5 MANVEL
STA. 6 GRAND FORKS
STA. 7 GRAND FORKS
STA. 8 CLIMAX
STA. 9 HALSTAD
STA. 10 GEORGETOWN
STA. 11 N. FARGO
STA. 12 S. FARGO
ICE
OPEN
COVERAGE
DISSOLVED OXYGEN AND BIOCHEMICAL OXYGEN DEMAND PARTS PER MILLION
DATES OF SAMPLING


BIOCHEMICAL OXYGEN DEMAND AND DISSOLVED OXYGEN
TRIBUTARY STATIONS
FIGURE 3
1938 NOV DEC JAN FEB MAR APR MAY JUNE 1939 JULY AUG SEP OCT NOV DEC JAN 1940 FEB MAR
STATION A - PEMBINA RIVER
FLOW STARTED
FLOW CEASED
D.O.
BOD
STATION B - TWO RIVERS
STATION C - TAMARACK RIVER
STATION D - PARK RIVER
STATION E - SNAKE RIVER
STATION F - FOREST RIVER
STATION H - RED LAKE RIVER
STATION I - GOOSE RIVER
STATION J - WILD RICE RIVER (MINNESOTA)
STATION K - BUFFALO RIVER
STATION L - SHEYENNE RIVER
DO
BOD
DISSOLVED OXYGEN AND BIOCHEMICAL OXYGEN DEMAND — PARTS PER MILLION
DATES OF SAMPLING


BIOCHEMICAL OXYGEN DEMAND
AND
DISSOLVED OXYGEN
MONTHLY AVERAGES
PLOTTED AGAINST
RIVER MILES
FIGURE 4
B.O.D.
D.O.
NOV. 1938
DEC. 1938
JAN. 1939
FEB. 1939
MAR. 1939
APR. 1939
MAY 1939
JUNE 1939
INTERNATIONAL BOUNDARY
DISSOLVED OXYGEN -- PER CENT SATURATION
BIOCHEMICAL OXYGEN DEMAND -- PARTS PER MILLION
300 270 240 210 180 150 120 90 60 30 0 30
FLOW
RIVER MILES



BIOCHEMICAL OXYGEN DEMAND
AND
DISSOLVED OXYGEN
MONTHLY AVERAGES
PLOTTED AGAINST
RIVER MILES
FIGURE 3
B.O.D.
D.O.
AUG. 1939
SEPT. 1939
OCT. 1939
NOV. 1939
DEC. 1939
JAN. 1940
FEB. 1940
MAR. 1940
INTERNATIONAL BOUNDARY
DISSOLVED OXYGEN -- PER CENT SATURATION
BIOCHEMICAL OXYGEN DEMAND -- PARTS PER MILLION
RIVER MILES
FLOW

NITRITE NITROGEN MONTHLY AVERAGES—PARTS PER MILLION (N)
Table X

Station	12	11	10	9	8	7	6	5	4	3	2	1
1938												
Nov.	.00	.21	.033	.027	.013	.00	Trace	.00	.00	.00	.00	.00
Dec.	Trace	.14	.07	.045	.02	.01	.01	.00	.00	.00	.00	.00
1939												
Jan.	Trace	.10	.055	.062	.04	.044	.02	.025	.03	.01	.007	.00
Feb.	.02	.06	.04	.014	.01—	.017	.02	.03	.02	.02	.025	.02
Mar.	.01—	.04	.018	Trace	.01	.01	.01—	.02	.013	.02+	.01+	.01+
Apr.	.013	.02—	.012	.01	.01	.01	.01	.01	.01+	.01—	.01—	Trace
May	.00	.01+	.0075	Trace	.00	.00	.00	Trace	.006	.00	.00	.00
June	Trace	.05	.03	Trace	.00	.005	Trace	.015	.023	.016	.016	.02
Aug.	.00	.09	.05	.00	.00	.01	Trace	.02	.00	.00	.00	.00
Sept.	.01—	.81	.03	Trace	Trace	.00	.01—	.01+	.01+	.01+	.00	.00
Oct.	.01+	.97	.075	Trace	Trace	.00	.004	.01—	.01—	.01—	.01—	.01
Nov.	Trace	.53	.068	.032	.018—	...	Trace	Trace	.01—	.01—	Trace	Trace
Dec.	.00	.30	.05	.04	.03	.02	Trace	Trace	Trace	Trace	Trace	Trace
1940												
Jan.	.00	.25	.05	.02	.03	...	.01	.03	.02	.00	.00	.00

NITRITE NITROGEN—MONTHLY AVERAGES—PARTS PER MILLION (N)
Table XI

Station	L	K	J	I	H	G	F	E	D	C	B	A
1938												
Nov.	0.021	0.00	0.00	....	0.00	0.005	.....	0.00	0.014	.....	0.00	....
Dec.	0.01	0.005	0.00	....	0.01	0.00	.....	0.00	0.00	.....	0.00	....
1939												
Jan.	Trace	0.00	0.015	....	0.012	.....	.....	0.00	0.00	.....	0.00	....
Feb.	0.005	0.00	0.005	....	0.003	.....	.....	0.00	.....	.....	.....	....
Mar.	0.012	0.004	Trace	....	Trace	.....	.....	0.005	.....	.....	.....	....
Apr.	0.005	0.01	Trace	0.015	Trace	.....	0.005	0.023	0.025	0.02	0.023	0.01
May	0.00	0.00	0.00	0.00	0.00	.....	0.00	0.005	0.00	0.00	0.00	0.00
June	0.01	0.00	0.002	0.015	0.00	.....	.....	0.00	0.00	.....	0.00	0.00
Aug.	0.10	0.00	0.00	....	Trace	.....	.....	0.00	0.00	.....	0.00	0.00
Sept.	0.06	0.00	0.00	....	Trace	0.25	0.00	0.00	0.00	.....	0.00	....
Oct.	0.255	Trace	0.00	....	0.00	0.266	0.00	0.00	0.02	.....	0.00	....
Nov.	0.03	0.00	0.005	....	0.00	0.012	0.05	.....	0.02	.....	0.01	....
Dec.	0.02	0.00	0.00	....	.....	.....	0.03	.....	.....	.....	.....	....
1940												
Jan.	0.01	0.01	0.00	....	0.00	.....	.....	.....	.....	.....	.....	....

MONTHLY TEMPERATURE—AVERAGE—°C.
Table XII

Station	12	11	10	9	8	7	6	5	4	3	2	1
1938												
Nov.	3.8	5.1	2.4	2.6	1.80	1.83	2.83	2.67	2.07	1.10	.9	.75
Dec.	0.75	1.4	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
1939												
Jan.	0.00	0.6	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
Feb.	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
Mar.	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
Apr.	4.0	3.75	3.5	3.5	3.25	3.7	2.75	2.75	3.00	3.00	3.25	2.8
May	16	16.2	15.6	15.75	17.5	17.2	16.8	17	16.8	15.5	14.9	14.75
June	21.4	21	20	20.7	20.2	21.5	21.5	21.5	21.5	21.5	21	19.5
Aug.	22	21	20	20	19	23	19	22	19	19	19	19
Sept.	21.3	20	17	17	17.5	18	16.5	16.67	16	16	16	16
Oct.	10.1	9.9	8.25	8.25	7.0	7.0	8.0	7.88	6.85	6.58	5.25	5.68
Nov.	1.8	3.6	1.8	1.7	.8	2.0	2.25	1.5	1.8	.5	0.50	1.25
Dec.	0.0	4.0	0.0	0.00	0.00	0.0	0	0.0	0.00	0.00	0.00	0
1940												
Jan.	0.0	0.00	0.0	0.00	0.00	0.0	0.00	0.0	0.0	0	0	0
Feb	0.0	0.00	0.0	0.00	0.00	0.0	0.00	0	0.00	0	0	0

MONTHLY TEMPERATURE—AVERAGES—°C
Table XIII

Station	A	B	C	D	E	F	G	H	I	J	K	L
1938												
Nov.	..	1°	..	1.5°	1°	...	5°+	1°—	...	1°—	1	2
Dec.	..	0.0	..	0.0	0.0	...	12.5°	0.0	...	0.0	0.0	0.0
1939												
Jan.	..	0.0	..	0.0	0.0	...	...	0.0	...	0.0	0.0	0.0
Feb.	..	..	..	..	0.0	...	...	0.0	...	0.0	0.0	0.0
Mar.	..	0.0	..	..	0.0	...	...	0.0	...	0.0	0.0	0.0
Apr.	4°	2°	2°—	3°	2°+	2°+	...	3°	3°+	3°	4°+	3°+
May	15°	14°	15°+	17°—	15°	15°	...	18°—	14°+	14°—	14°	14°+
June	19°	19°+	..	18°+	21°+	...	...	21°—	17°	20°	19°	20°—
Aug.	21°	18°	..	18°	23°	...	...	23°	...	18°	19°	20°
Sept.	..	14°—	..	14°	8°	8°	18°	16°	...	21°	16°+	17°+
Oct.	..	6°	..	5°—	8°—	8°—	20	7°+	...	16°+	8°+	8°+
Nov.	..	1°	..	1°	...	0+	18°	2°—	...	8°+	2°—	1°+
Dec.	..	..	..	..	...	0+	...	0.0	...	2°+	0.0	2°
1940												
Jan.	..	..	..	..	...	...	...	0.0	...	0.0	0.0	0.0
Feb.	..	..	..	..	...	...	...	0.0	...	0.0	0.0	0.0
Mar.	..	..	..	..	...	...	...	0.0	...	...	...	...

TURBIDITY—MONTHLY AVERAGES—P.P.M.
Table XIV

Station	12	11	10	9	8	7	6	5	4	3	2	1
1938												
Nov.	17	22	10	8	12	7	15	38	45	70	60	45
Dec.	10	37	10	19	20	10	87	15	20	25	24	26
1939												
Jan.	7	17	14	16	20	13	17	8	12	12	22	21
Feb.	9	10	9	12	13	11	10	15	8	15	10	10
Mar.	54	63	58	59	13	9	12	7	5	6	6	7
Apr.	72	116	165	304	421	322	321	282	340	337	410	470
May	85	104	154	154	140	76	97	80	81	85	110	187
June	66	61	125	144	160	77	102	120	107	23	50	124
Aug.	30	90	100	100	100	70	40	90	100	15	60	70
Sept.	37	60	258	113	222	43	60	153	270	135	167	140
Oct.	42	75	137	90	97	35	44	32	62	55	67	82
Nov.	25	40	37	62	78	16	57	42	45	57	86	72
Dec.	20	20	30	40	60	30	60	60	25	20	50	50
1940												
Jan.	..	..	..	..	...	...	...	...	...	...	...	...
Feb.	..	..	..	..	...	...	...	...	...	...	...	...

TURBIDITY—MONTHLY AVERAGES—P.P.M.
Table XV

Station	A	B	C	D	E	F	G	H	I	J	K	L
1938												
Nov.	..	55	..	60	60	...	...	5	...	17	13	17
Dec.	..	37	..	29	48	...	2,337	12	...	10	16	15
1939												
Jan.	..	72	..	60	70	...	...	17	...	12	35	11
Feb.	..	..	..	..	50	...	...	12	...	11	22	11
Mar.	..	..	..	..	65	...	...	15	...	18	37	58
Apr.	75	184	88	192	125	65	...	62	92	106	97	143
May	22	55	117	70	77	64	...	98	79	75	20	62
June	8	11	..	128	47	...	...	109	90	64	16	65
Aug.	40	90	..	15	90	...	...	40	...	70	90	100
Sept.	..	137	..	243	...	10	240	47	...	63	40	70
Oct.	..	55	..	105	...	25	150	42	...	40	32	31
Nov.	..	50	..	80	...	111	1,525	20	...	20	25	16
Dec.	..	..	..	..	...	50	1,100	60	...	15	30	20
1940												
Jan.	..	..	..	..	...	...	...	...	...	...	...	...
Feb.	..	..	..	..	...	...	...	...	...	...	...	...

MONTHLY AVERAGE—pH
Table XVI

Station	12	11	10	9	8	7	6	5	4	3	2	1
1938												
Nov.	8.4	7.8	8.0	8.1	8.1	8.5	8.1	8.2	7.9	7.9	8.0	8.2
Dec.	7.9	7.75	7.6	7.7	7.7	8.15	7.9	7.8	7.5	7.8	7.75	7.7
1939												
Jan.	7.7	7.9	7.7	7.8	7.6	7.7	7.6	7.6	7.6	7.6	7.5	7.6
Feb.	7.7	7.8	7.7	7.6	7.6	7.7	7.8	7.5	7.6	7.5	7.5	7.6
Mar.	7.54	7.56	7.6	7.6	7.5	7.5	7.45	7.55	7.6	7.5	7.5	7.6
Apr.	7.9	7.75	7.8	7.7	7.7	7.9	7.9	7.7	7.7	7.9	7.9	7.8
May	8.4	8.3	8.4	8.5	8.4	8.4	8.3	8.4	8.3	8.4	8.45	8.35
June	8.4	8.1	8.4	8.36	8.4	8.2	8.2	8.1	8.0	8.4	8.5	8.5
Aug.	8.6	8.6	8.6	8.4	8.4	8.4	8.2	7.7	7.7	8.3	8.4	8.5
Sept.	8.5	7.7	8.5	8.5	8.5	8.5	8.3	8.2	8.26	8.4	8.4	8.4
Oct.	8.35	7.95	8.3	8.5	8.4	8.3	8.1	7.8	7.85	8.25	8.4	8.3
Nov.	8.46	8.1	8.3	8.46	8.5	8.45	8.0	8.0	8.0	8.2	8.2	8.3
Dec.	8.0	7.8	8.0	8.6	8.6	8.4	7.8	7.7	7.7	7.7	7.8	8.0
1940												
Jan.	8.0	7.8	7.6	7.7	7.8	8.4	8.0	...	...	...	...	...
Feb.	..	..	..	..	...	...	...	...	...	...	...	...

MONTHLY AVERAGE—pH
Table XVII

Station	A	B	C	D	E	F	G	H	I	J	K	L
1938												
Nov.	...	7.6+	...	8.0—	7.7	...	7.2	8.3+	...	8.1	8.0+	8.1—
Dec.	...	7.4	...	7.7+	7.6	...	7.4—	7.75	...	7.8—	7.65	7.7
1939												
Jan.	...	7.3+	...	7.5+	7.4	...	...	7.6—	...	7.5	7.4	7.5+
Feb.	...	...	...	...	7.4	...	...	7.55	...	7.5—	7.5—	7.55
Mar.	...	...	...	...	7.3	...	...	7.45	...	7.5	7.4—	7.5
Apr.	7.8	7.5	7.5—	8.0	7.6—	8.5	...	7.8	7.8—	7.9+	7.8+	7.8—
May	8.2—	8.3—	8.4	8.5+	8.2+	8.5—	...	8.3—	8.45	8.4	8.4+	8.35
June	8.0+	8.2—	...	8.5+	8.4	...	...	8.4—	8.1	8.4	8.4+	8.3+
Aug.	7.9	8.4	...	8.6	8.6	...	...	8.4	...	8.5	8.5	8.4
Sept.	...	8.4+	...	8.5—	8.4	8.4	7.2	8.4	...	8.4+	8.5—	8.4
Oct.	...	8.3	...	8.5	8.3+	8.3—	6.7	8.3—	...	8.0	7.95	8.05
Nov.	...	7.8	...	8.4	...	8.4	6.8—	8.3	...	8.2+	8.2	8.4+
Dec.	...	...	...	...	...	7.9	7.0	8.0	...	8.2	8.0	8.4
1940												
Jan.	...	...	...	...	...	...	...	8.2	...	7.7	7.7	7.6
Feb.	...	...	...	...	...	...	...	...	...	...	...	...

CHEMICAL ANALYSIS OF WATER IN RED RIVER AND ITS TRIBUTARIES BEFORE AND AFTER SPRING BREAKUP
Table XVIII

Station	Date	Free Ammonia	Albuminoid Ammonia	Nitrite	Nitrate	Total Solids	Ignited Solids	Suspended Solids	Alkalinity as $CaCO_3$	Bicarb.	Calcium	Magnesium	Sodium	Chloride	Sulphate	Total Hardness as $CaCO_3$
12	3-22-39	0.512	0.413	0.001	0.622	351	292	5	274	334	38	47	30	7	75	288
	6-12-39	0.300	0.240	0.000	0.147	290	251	19	234	286	49	42	13	7	79	295
11	3-22-39	1.568	0.420	0.01	0.565	375	324	41	248	302	44	47	21	10	78	315
	6-12-39	1.440	0.480	0.025	0.316	328	290	23	230	281	55	43	7	17	74	314
L	3-22-39	1.355	0.365	0.006	0.367	697	658	5	314	383	95	33	97	89	140	372
	6-12-39	0.240	0.620	0.010	0.226	583	540	43	265	324	78	42	61	67	135	368
K	3-22-39	0.397	0.245	0.001	0.423	650	568	54	402	490	124	69	None	8	169	595
	6-12-39	0.100	0.200	0.000	0.169	572	536	14	273	333	89	64	16	13	220	485
J	3-22-39	0.190	0.545	0.001	0.621	594	467	46	440	537	107	66	21	17	116	540
	6-12-39	0.100	0.200	0.000	0.158	310	288	0	224	274	57	41	None	5	47	311
9	3-22-39	1.500	0.590	0.001	0.678	448	383	19	315	384	61	51	16	20	52	361
	6-12-39	0.080	0.340	0.000	0.124	396	255	30	225	275	56	46	17	20	60	329
7	3-23-39	1.265	0.410	0.005	0.395	444	317	28	297	365	62	55	None	8	64	380
	6-16-39	0.200	0.360	0.005	0.194	301	294	17	136	166	41	15	36	17	80	164
H	3-23-39	0.423	0.400	0.001	0.452	342	254	22	340	293	65	40	None	4	63	326
	6-16-39	0.120	0.420	0.000	0.147	327	267	50	175	214	59	26	None	8	45	254
4	3-23-39	1.140	0.495	0.003	0.482	392	274	19	275	336	68	43	None	8	59	288
	6-16-39	0.220	0.300	0.005	0.180	311	275	41	154	188	50	18	92	23	52	199
1	6-15-39	0.080	0.360	0.010	0.282	325	266	85	202	246	63	30	33	37	100	286

MOST PROBABLE NUMBERS OF COLIFORM ORGANISMS PER 100 cc.
MONTHLY AVERAGES
Table XIX

Date	12	11	10	9	8	7	6	5	4	3	2	1
1938 Nov.	68	*3 Ind.	960	888	533	3.6	*2 24,000	*3 24,000	*3 24,000	*1 8,620	461	12.7
Dec.	110.2	*4 Ind.	4,143	632	324.8	13.7	*3 24,000	*3 19,150	*3 18,600	*2 13,257	*2 17,500	3.866
1939 Jan.	127	*4 Ind.	*1 14,250	1,320	963	785.7	8,000	10,007	7,800	2,735	5,577.5	*1 12,726
Feb.	827	*4 Ind.	*3 20,750	4,612	776.5	17.2	*1 11,050	*1 24,000+	3,376.8	240	80.1	84
Mar.	1,193	25,460	16,740	3,746	1,104	511	*1 13,675	*1 13,200	2,483.3	240	299	35
Apr.	341	***1 72,075	23,075	4,600	2,032	415	16,100	8,750	5,407.5	4,840	1,461	5,025
May	423	***1 114,250	5,075	667	43.5	988.8	49,342	189,866	8,926	827.5	182	120.5
June	528.6	1,737,860	18,600	1,113	1,475	289.7	15,500	38,966	6,822.5	113.8	136.4	153.2
Aug.	240	*1 Ind.	2,400	93	150	240	2,400	210	150	240	240	93
Sept.	1,863	***1 1,680,000	1,080	693	9,513	1,087	*2 30,333	350,200	3,910	273.3	473.3	317.7
Oct.	299	1,822,500	963	330	341	9,565	3,024,000	893,250	***1 460,000	*1 6,940	548.2	505
Nov.	45	1,041,000,000	*1 5,810	114	656.5	7,756	927,500	347,500	1,313,333	4,232.5	3,068	*1 8.750
Dec.	9.1	330,000,000	7,300	23	91	**1 Ind.	2,000,000	3,600	Ind.	**1 930	330	109.5

*Indeterminate samples: More than 24,000 per 100 cc.
**Indeterminate samples: Less than 360 per 100 cc.
***Indeterminate samples: More than 240,000 per 100 cc.

MOST PROBABLE NUMBER OF COLIFORM ORGANISMS PER 100 cc.
MONTHLY AVERAGES
Table XX

Month	A	B	C	D	E	F	G	H	I	J	K	L
1938							*2					
Nov.		625		316	12.3		24,000+	261		421	109	955
				*1			*4	*3				
Dec.		1,945		12,100	21		24,000+	20,750+		321.5	199	17,600
1939												
Jan.		902.5		307	28.7			2,848		76	275	1,907
Feb.					3			4,775		305.5	1,032.5	3,422
Mar.					3.6			5,550		372.6	2,782.6	5,108
Apr.	304	462.5	421	885	2,530	121.8		2,266	767.5	214	325	8,210
May	420	555	6,392	80	641	413		286.5	2,006	1,386	240	875
June	152	111		627	238			195	4,300	1,858	448	3,606
Aug.		930		23	75			430		200	200	430
							*1	*1				
Sept.		680		1,081	2,400	240	24,000+	8,151		1,263	4,060	1,177
Oct.		52.5		87	62—	1,253	62,680,000+	15,106		242.5	2,725	1,320
Nov.		750		23		2,792	616,100,000	5,765		144.4	840	5,681
Dec.						3.6	21,000,000,000+			91	73	1,500

*Indeterminate samples: more than 24,000 per 100 cc.
**Indeterminate samples: less than 360 per 100 cc.
***Indeterminate samples: more than 240,000 per 100 cc.

BASE DATA—Table XXI—12

Station 12	(1) Ave. Daily Flow C.F.S.	(2) No. of Samples	(3) Ave. NO_2-N P.P.M.	(4) Ave. Temp. °C.	(5) Ave. Turb. P.P.M.	(6) Ave. pH	(7) Ave. BOD 20° 5 Day P.P.M.	(8) Dissolved Oxygen P.P.M.	(9) Dissolved Oxygen % Sat.	(10) Daily Average Pounds per Day D.O.	(11) Daily Average Pounds per Day B.O.D.	(12) Oxygen Balance Pounds (10)-(11)	(13) Oxygen Balance P.P.M. (8)-(7)	(14) Coliform Organisms M.P.N. per 100 cc.	(15) Coliform Organisms M.P.N. Quant. Units
1938															
Nov.	23	5	0.00	3.8	17	8.4	4.5	12	91	1,490	559	931	7.5	68	2
Dec.	25	4	Trace	0.75	10	7.9	3.3	9.2	64	1,242	446	796	5.9	110.2	3
1939															
Jan.	97	4	Trace	0.0	7	7.7	2.2	8.9	60.8	4,662	1,152	3,510	6.7	127	12
Feb.	102	4	0.02	0.0	9	7.7	1.7	10.4	71	5,728	936	4,792	8.7	827	84
Mar.	743	5	0.01—	0.0	54	7.54	2.5	9.7	66.3	38,918	10,031	28,887	7.2	1,193	886
Apr.	710	4	0.013	4.0	72	7.9	4.5	11.5	88	21,091	8,253	12,838	7.0	341	242
May	219	4	0.00	16	85	8.4	2.5	8.4	84.4	9,933	2,957	6,976	5.9	423	93
June	135	4	Trace	21.4	66	8.4	4.2	7.8	87.4	5,686	3,062	2,624	3.6	528.6	71
Aug.	18	1	0.00	22	30	8.6	5.1	8.8	100	855	496	359	3.7	240	4
Sept.	5.2	3	0.01—	21.3	37	8.5	4.8	6.5	72.6	183	135	48	1.7	1,863	10
Oct.	13	4	0.01—	10.1	42	8.35	3.6	8.6	76	604	253	351	5.0	299	6
Nov.	21	5	Trace	1.8	25	8.46	4.2	12.8	91.8	1,451	476	975	8.6	45	0.9
Dec.	17	1	0.00	0.0	20	8.0	2.8	12.6	86.1	1,157	257	900	9.8	9.1	0.1
1940															
Jan.	4.5	2	0.00	0.0	..	8.0	3.3	9.2	62.9	224	80	144	5.9	...	...
Feb.	11	1	....	0.0	..	...	2.6	5.3	36.2	315	154	161	2.7	...	...
Mar.	40	1	....	...	..	...	...	...	...	......	......	......	...	...	...
SEASONAL AVERAGES															
A	...	17	.008	.19	20	7.71	2.43	9.55	65.53	12,637	3,141	9,498	7.15	564.3	248
B	...	12	.004	13.8	74	8.18	3.80	9.23	86.60	12,237	4,757	7,479	5.50	430.9	135
C	...	4	.005	21.7	34	8.55	4.95	7.65	86.30	519	315	204	2.70	1,051.5	7

BASE DATA—Table XXI—11

Station 11	(1) Ave. Daily Flow C.F.S.	(2) No. of Samples	(3) Ave. NO_3-N P.P.M.	(4) Ave. Temp. °C.	(5) Ave. Turb. P.P.M.	(6) Ave. pH	(7) Ave. BOD 20° 5 Day P.P.M.	(8) Dissolved Oxygen P.P.M.	(9) Dissolved Oxygen % Sat.	(10) Daily Average Pounds per Day D.O.	(11) Daily Average Pounds per Day B.O.D.	(12) Oxygen Balance Pounds (10)-(11)	(13) Oxygen Balance P.P.M. (8)-(7)	(14) Coliform Organisms M.P.N. per 100 cc.	(15) Coliform Organisms M.P.N. Quant. Units
1938															
Nov.	23	5	0.21	5.1	22	7.8	13.1	9.3	72.8	1,155	1,627	— 572	— 3.8	Ind. 24,000+	552
Dec.	25	4	0.14	1.4	37	7.75	12.3	6.5	46.2	878	1,661	— 783	— 5.8	Ind. 24,000+	600
1939															
Jan.	98	4	0.10	0.6	17	7.9	11.4	8.7	60.4	4,604	6,033	—1,429	— 2.7	Ind. 24,000+	2,352
Feb.	102	4	0.06	0.0	10	7.8	4.8	9.8	67	5,398	2,644	2,754	5.0	Ind. 24,000+	2,448
Mar.	743	5	0.04	0.0	63	7.56	5.8	9.8	67	39,320	23,270	16,050	4.0	25,460	18,917
Apr.	711	4	0.02+	3.75	116	7.75	5.2	11.2	85.3	43,001	19,965	23,036	6.0	72,075	51,245
May	218	4	0.01+	16.2	104	8.3	4.6	8.6	86.5	10,124	5,415	4,709	4.0	114,250	24,907
June	135	4	0.05	21	61	8.1	5.7	7.7	85.6	5,613	4,155	1,438	2.7	1,737,860	234,611
Aug.	17	1	0.09	21	90	8.6	7.4	4.9	54.5	450	679	— 229	— 2.5	Ind. 24,000+	408
Sept.	5.2	3	0.18	20	60	7.7	13.7	2.5	27.3	70	385	— 315	—11.2	1,680,000	8,736
Oct.	15	4	0.97	9.9	75	7.95	16.4	8.4	74.1	680	1,328	— 648	— 8.0	1,822,500	27,338
Nov.	22	5	0.53	3.6	40	8.1	15.4	8.8	66.3	1,045	1,830	1,785	— 6.6	1,041x10^6	229x10^5
Dec.	19	1	0.30	4.0	20	7.8	20.7	8.8	67.0	903	2,124	—1,221	—11.9	330x10^6	627x10^4
1940															
Jan.	5.6	2	0.25	0.0	..	7.8	26.0	3.2	21.9	97	786	— 689	—22.8	...	...
Feb.	12	1	....	0.0	..	...	24.7	2.6	17.8	168	1,601	—1,533	—22.1	...	....
Mar.	41	1	....	...	..	...	...	....	...	....	....	....	...	...	..
SEASONAL AVERAGES															
A	17	...	.085	.04	31.8	7.75	8.58	8.70	60.15	12,550	8,402	4,148	.12	Ind. 24,385	6,079
B	12	...	.027	13.65	73.7	8.05	5.17	9.17	85.80	19,579	9,845	9,727	4.23	641,395	103,588
C	4	...	.450	20.50	75.5	8.15	10.55	3.70	40.90	260	532	— 272	— 6.85	Ind. 852,000	4,072

BASE DATA—Table XXI—10

Station	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10) Daily Average Pounds per Day	(11)	(12) Oxygen Balance	(13)	(14) Coliform Organisms	(15)
10	Ave. Daily Flow C.F.S.	No. of Samples	Ave. NO_2-N P.P.M.	Ave. Temp. °C.	Ave. Turb. P.P.M.	Ave. pH	Ave. BOD 20° 5 Day P.P.M.	Dissolved Oxygen P.P.M.	Dissolved Oxygen % Sat.	D.O.	B.O.D.	Pounds (10)-(11)	P.P.M. (8)-(7)	M.P.N. per 100 cc.	M.P.N. Quant. Units
1938															
Nov.	45	5	0.033	2.4	10	8.0	3.2	10.7	78.1	2,600	778	1,922	7.5	960	43
Dec.	38	4	0.07	0.0	10	7.6	1.6	1.7	11.6	349	328	21	0.1	4,143	157
1939															
Jan.	95	4	0.055	0.0	14	7.7	2.8	4.2	28.7	2,155	1,436	719	1.4	14,250	1,354
Feb.	102	4	0.04	0.0	9	7.7	3.7	6.7	45.8	6,834	3,774	3,060	3.0	20,750	2,117
Mar.	855	5	0.018	0.0	58	7.6	4.4	6.8	46.6	31,396	20,315	11,081	2.4	16,740	14,313
Apr.	1,420	4	0.012	3.5	165	7.8	5.5	11.2	84.0	85,881	42,174	43,707	5.7	23,075	32,767
May	320	4	0.0075	15.6	154	8.4	2.7	8.3	82.7	14,342	4,666	9,676	5.6	5,075	1,624
June	234	4	0.03	20	125	8.4	5.1	8.0	87.3	10,108	6,444	3,664	2.9	18,600	4,352
Aug.	25	1	0.05	20	100	8.6	9.5	10.2	111.0	1,377	1,283	94	0.7	2,400	60
Sept.	9	3	0.03	17	258	8.5	6.6	9.4	96.5	457	321	136	2.8	1,080	10
Oct.	22	4	0.075	8.25	137	8.3	7.5	8.6	72.9	1,022	891	131	1.1	963	21
Nov.	38	5	0.068	1.8	37	8.3	3.7	12.0	86.2	2,462	759	1,703	8.3	5,810	221
Dec.	34	1	0.05	0.0	30	8.0	6.1	9.3	63.6	1,707	1,120	587	3.2	7,300	248
1940															
Jan.	5	2	0.05	0.0	..	7.6	7.5	.9	6.1	24	203	— 179	— 6.6	.....	.....
Feb.	11	1	....	0.0	..	...	11.0	0.0	0.0	0.00	653	— 653	—11.0	.....	.....
Mar.	59	1	....	...	..	...	13.2	1.14	16.7	363	4,206	—3,843	—12.06	.....	.....
SEASONAL AVERAGES															
A	...	17	0.046	0.0	23	7.65	3.12	4.85	33.2	10,184	6,463	3,745	+1.73	13,971	4,485
B	...	12	0.016	13.0	148	8.20	4.43	9.17	84.7	36,777	17,761	19,015	+4.47	15,583	12,914
C	...	4	0.04	18.5	179	8.55	8.05	9.80	103.7	912	802	115	+1.75	1,740	35

BASE DATA—Table XXI—9

Station	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10) Daily Average Pounds per Day	(11)	(12) Oxygen Balance	(13)	(14) Coliform Organisms	(15)
9	Ave. Daily Flow C.F.S.	No. of Samples	Ave. NO_2-N P.P.M.	Ave. Temp. °C.	Ave. Turb. P.P.M.	Ave. pH	Ave. BOD 20° 5 Day P.P.M.	Dissolved Oxygen P.P.M.	Dissolved Oxygen % Sat.	D.O.	B.O.D.	Pounds (10)-(11)	P.P.M. (8)-(7)	M.P.N. per 100 cc.	M.P.N. Quant. Units
1938															
Nov.	62	5	0.027	2.6	8	8.1	1.3	11.36	83.4	3,803	435	3,368	10.06	888	55
Dec.	57	4	0.045	0.0	19	7.7	1.7	2.2	15.0	677	523	154	.5	632	36
1939															
Jan.	98	4	0.062	0.0	16	7.8	2.0	1.9	130	1,005	1,058	8	.1	1,320	129
Feb.	114	4	0.014	0.0	12	7.6	1.8	3.3	22.6	2,031	1,108	923	1.5	4,612	526
Mar.	723	5	Trace	0.0	59	7.6	3.4	4.1	28.1	16,007	13,274	2,733	.7	3,746	2,708
Apr.	1,830	4	0.01	3.5	304	7.7	5.5	11.2	84.0	110,678	54,351	56,327	5.7	4,600	8,418
May	429	4	Trace	15.75	154	8.5	3.4	10.1	101.0	23,398	7,876	15,522	6.7	667	286
June	318	5	Trace	20.7	144	8.36	3.6	8.3	91.8	14,253	6,182	8,071	4.7	1,113	354
Aug.	42	1	0.00	20	100	8.4	2.7	6.2	67.7	1,406	612	794	3.5	93	4
Sept.	21	3	Trace	17	113	8.5	3.2	8.6	88.3	975	363	612	5.4	693	15
Oct.	33	4	Trace	8.25	90	8.5	6.7	10.5	88.9	1,871	1,194	677	3.8	330	11
Nov.	49	5	0.032	1.7	62	8.46	5.1	15.0	107.4	3,969	1,349	2,620	9.9	114	6
Dec.	47	1	0.04	0.0	40	8.6	3.1	15.1	103.0	3,832	787	3,045	12.0	23	1
1940															
Jan.	11	2	0.02	0.0	..	8.7	7.7	3.7	25.3	220	457	—237	—4.0	.....	.....
Feb.	14	1	....	0.0	..	...	12.6	0.0	0.0	000	953	—953	—12.6	.....	.....
Mar.	77	1	....	...	..	...	12.0	0.0	0.0	000	4,990	—4,990	—12.0	.....	.....
SEASONAL AVERAGES															
A	...	17	0.035	0.0	26.5	7.67	2.22	2.87	19.67	4,930	3,991	950	+0.65	2,527	850
B	...	13	0.006	13.32	201	8.20	4.17	9.87	92.3	49,442	22,803	26,640	+5.70	2,127	3,017
C	...	4	Trace	18.5	106	8.45	2.95	7.40	78.0	1,190	488	703	+4.45	393	9.5

BASE DATA—Table XXI—8

Station 8	(1) Ave. Daily Flow C.F.S.	(2) No. of Samples	(3) Ave. NO_2-N P.P.M.	(4) Ave. Temp. °C.	(5) Ave. Turb. P.P.M.	(6) Ave. pH	(7) Ave. BOD 20° 5 Day P.P.M.	(8) Dissolved Oxygen P.P.M.	(9) Dissolved Oxygen % Sat.	(10) Daily Average Pounds per Day: D.O.	(11) Daily Average Pounds per Day: B.O.D.	(12) Oxygen Balance: Pounds (10)-(11)	(13) Oxygen Balance: P.P.M. (8)-(7)	(14) Coliform Organisms: M.P.N. per 100 cc.	(15) Coliform Organisms: M.P.N. Quant. Units
1938															
Nov.	62	4	0.013	1.80	12	8.1	1.7	12.96	93.0	4,339	569	3,770	11.26	533	33
Dec.	56	4	0.02	0.0	20	7.7	1.4	2.4	16.4	791	461	330	1.0	324.8	18
1939															
Jan.	85	4	0.04	0.0	20	7.6	2.3	.5	3.4	229	1,056	— 827	— 1.8	963	82
Feb.	106	4	0.01—	0.0	13	7.6	1.4	1.7	11.6	973	801	172	.3	776.5	82
Mar.	626	5	0.01	0.0	13	7.5	1.8	2.8	19.2	9,464	6,084	3,380	1.0	1,104	991
Apr.	2,020	4	0.01	3.5	421	7.7	6.2	10.8	81.0	117,806	67,630	50,176	4.6	2,032	4,105
May	451	4	0.00	17.5	140	8.4	3.4	8.8	88.0	21,431	8,280	13,151	5.4	43.5	20
June	344	5	0.00	20.2	160	8.4	3.3	7.9	87.4	14,675	6,130	8,545	4.6	1,475	507
Aug.	41	1	0.00	19	100	8.4	2.8	7.5	81.8	1,661	619	1,042	4.7	150	6
Sept.	17	3	Trace	17.5	222	8.5	3.7	8.2	84.2	753	340	413	4.5	9,513	162
Oct.	26	4	Trace	7.0	97	8.4	4.3	10.2	86.4	1,432	604	828	5.9	341	9
Nov.	46	5	0.018	.8	78	8.5	10.1	15.3	109.6	3,801	2,509	1,292	5.2	656.5	30
Dec.	38	1	0.03	0.0	60	8.6	4.2	15.5	106	3,181	862	2,319	11.3	91	3
1940															
Jan.	14	2	0.03	0.0	..	7.8	6.4	5.6	38.3	423	484	— 61	— .8	.....	...
Feb.	8	1	....	0.0	..	...	22.4	0.0	0.0	0.00	968	— 968	—22.4	.....	.....
Mar.	80	1	....	...	..	...	21.3	0.0	0.0	0.00	9,202	—9,202	—21.3	.....	...
SEASONAL AVERAGES															
A	...	17	0.02	0.0	16.5	7.6	1.72	1.85	12.67	2,864	2,100	9,945	+0.13	792	293
B	...	13	0.003	13.73	240	8.17	4.30	9.17	85.47	51,304	27,345	23,957	+4.87	1,183	1,158
C	...	4	Trace	18.25	161	8.45	3.25	7.85	83.0	1,207	479	728	+4.60	4,831	84

BASE DATA—Table XXI—7

Station 7	(1) Ave. Daily Flow C.F.S.	(2) No. of Samples	(3) Ave. NO_2-N P.P.M.	(4) Ave. Temp. °C.	(5) Ave. Turb. P.P.M.	(6) Ave. pH	(7) Ave. BOD 20° 5 Day P.P.M.	(8) Dissolved Oxygen P.P.M.	(9) Dissolved Oxygen % Sat.	(10) Daily Average Pounds per Day D.O.	(11) Daily Average Pounds per Day B.O.D.	(12) Oxygen Balance Pounds (10)-(11)	(13) Oxygen Balance P.P.M. (8)-(7)	(14) Coliform Organisms M.P.N. per 100 cc.	(15) Coliform Organisms M.P.N. Quant. Units
1938															
Nov.	59	3	0.00	1.83	7	8.5	3.2	13.2	94.9	4,206	1,019	3,187	10	3.6	.2
Dec.	59	4	0.01	0.0	10	8.15	2.7	9.9	67.7	3,154	860	2,294	7.2	13.7	.8
1939															
Jan.	78	5	0.044	0.0	13	7.7	2.1	1.1	7.52	463	885	— 422	— 1.0	785.7	61
Feb.	99	4	0.017	0.0	11	7.7	1.3	.9	6.17	481	695	— 214	— 0.4	17.2	1.7
Mar.	274	4	0.01	0.0	9	7.5	1.8	1.1	7.5	1,627	2,663	—1,036	— 0.7	511	140
Apr.	2,450	4	0.01	3.25	322	7.9	5.0	10.1	75.4	133,623	66,150	67,473	5.1	415	1,017
May	458	5	0.00	17.2	76	8.4	2.7	8.3	85.7	20,528	6,678	13,850	5.6	988.8	453
June	366	4	0.005	21.5	77	8.2	2.8	6.0	67.4	11,858	5,534	6,324	3.2	289.7	106
Aug.	38	1	0.01	23	70	8.4	4.0	6.5	74.8	1,334	820	514	2.5	240	9
Sept.	16	3	0.00	18	43	8.5	3.9	7.6	79.6	657	337	320	3.7	1,087	17
Oct.	24	4	0.00	7.0	35	8.3	4.1	8.6	70.7	1,115	531	584	4.5	9,565	230
Nov.	41	4	....	2.0	16	8.45	3.2	10.9	78.6	2,413	708	1,705	7.7	7,756	318
Dec.	28	2	0.02	0.0	30	8.4	3.9	19.9	136	3,009	590	2,419	16.0	Ind.	.....
1940															
Jan.	9	2	....	0.0	..	8.4	3.0	18.6	127	904	146	758	15.6	.....	.....
Feb.	5	1	....	0.0	..	...	...	12.0	82.1	194	.....	.....	....	.....	.....
Mar.	73	...	....	...	..	...	...	...	...	....	.....	.....	....	.....	.....
SEASONAL AVERAGES															
A	127	17	0.021	0.0	11	7.76	1.97	3.25	22.22	1,431	1,276	622	1.28	332	51
B	1,091	13	0.005	13.98	158	8.17	3.5	8.13	76.17	55,336	26,121	9,739	4.63	564	394
C	27	4	0.005	20.5	56	8.45	3.95	7.05	77.2	996	579	578	3.10	663	13

BASE DATA—Table XXI—6

Station 6	(1) Ave. Daily Flow C.F.S.	(2) No. of Samples	(3) Ave. NO_2-N P.P.M.	(4) Ave. Temp. °C.	(5) Ave. Turb. P.P.M.	(6) Ave. pH	(7) Ave. BOD 20° 5 Day P.P.M.	(8) Dissolved Oxygen P.P.M.	(9) Dissolved Oxygen % Sat.	(10) Daily Average Pounds per Day D.O.	(11) Daily Average Pounds per Day B.O.D.	(12) Oxygen Balance Pounds (10)-(11)	(13) Oxygen Balance P.P.M. (8)-(7)	(14) Coliform Organisms M.P.N. per 100 cc.	(15) Coliform Organisms M.P.N. Quant. Units
1938															
Nov.	190	5.3*	Trace	2.83	15	8.1	19.0	10.95	80.8	11,240	19,494	— 8,254	— 8.05	24,000	4,560
Dec.	199	3	0.01	0.0	87	7.9	17.3	7.9	54	8,490	18,600	—10,110	— 9.4	24,000	4,776
1939															
Jan.	237	5	0.02	0.0	17	7.6	2.7	3.7	25.3	4,739	3,459	1,280	1.0	8,000	1,896
Feb.	229	4	0.02	0.0	10	7.8	2.3	2.5	17.1	3,091	2,844	147	0.2	11,050	2,530
Mar.	455	4	0.01—	0.0	12	7.45	2.0	2.1	14.4	5,046	4,806	240	0.1	13,675	6,222
Apr.	3,126	4	0.01	3.7	321	7.9	6.1	9.5	70.1	160,363	102,970	57,393	3.4	16,100	50,329
May	912	5	0.00	16.8	97	8.3	3.1	7.3	74.7	35,951	15,267	20,684	4.2	49,342	45,000
June	687	4	Trace	21.5	102	8.2	2.2	5.0	56.1	18,549	8,162	10,387	2.8	15,400	10,580
Aug.	118	1	Trace	23.	40	8.2	4.8	5.5	63.4	3,505	3,059	446	0.7	2,400	283
Sept.	225	3	0.01—	16.5	60	8.3	3.7	6.7	68.1	8,140	4,495	3,645	3.0	30,333	6,825
Oct.	334	5	0.004	8.0	44	8.1	12.6	9.0	75.9	16,232	22,725	— 6,493	— 3.6	3,024,000	1,010,016
Nov.	333	4	Trace	2.25	57	8.0	20.4	11.5	83.6	20,679	36,383	—15,704	— 8.9	927,500	308,857
Dec.	315	1	Trace	0.0	60	7.8	21.5	11.5	78.6	19,561	36,571	—17,010	—10.0	2,000,000	630,000
1940															
Jan.	175	2	0.01	0.0	..	8.0	17	10.1	69.0	9,544.5	1,606.5	7,938.0	— 6.9	.....	.....
Feb.	186	1	....	0.0	..	...	...	6.75	46.2	6,780	.....	.....	.....	.....	.....
Mar.	...	...	....	...	..	...	...	...	...	....	.....	.....	.....	.....	.....
SEASONAL AVERAGES															
A	280	16	0.015	0.0	31	7.69	6.1	4.05	27.7	5,341	7,427	— 2,086	— 2.05	14,181	3,856
B	1,575	13	0.004	14	173	8.13	3.8	7.27	66.97	71,621	42,133	29,488	3.47	26,947	35,303
C	171	4	0.005	19.75	50	8.25	4.25	6.1	65.75	5,822	3,777	2,045	1.85	16,366	3,554

*Number of B. O. D. samples when the number of D. O. samples is greater than number of B. O. D. samples.

BASE DATA—Table XXI—5

Station	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10) Daily Average Pounds per Day	(11)	(12) Oxygen Balance	(13)	(14) Coliform Organisms	(15)
5	Ave. Daily Flow C.F.S.	No. of Samples	Ave. NO_2-N P.P.M.	Ave. Temp. °C.	Ave. Turb. P.P.M.	Ave. pH	Ave. BOD 20° 5 Day P.P.M.	Dissolved Oxygen P.P.M.	Dissolved Oxygen % Sat.	D.O.	B.O.D.	Pounds (10)-(11)	P.P.M. (8)-(7)	M.P.N. per 100 cc.	M.P.N. Quant. Units
1938															
Nov.	190	6, 3*	0.00	2.7	38	8.2	9.9	6.11	44.9	6,269	10,157	— 3,888	— 3.79	24,000	4,560
Dec.	198	4	0.00	0.0	15	7.8	8.7	3.4	23.2	3,635	9,302	— 5,667	— 5.3	19,150	3,792
1939															
Jan.	235	4	0.025	0.0	8	7.6	5.4	2.9	19.8	3,680	6,853	— 3,173	— 2.5	10,007	2,352
Feb.	232	3	0.03	0.0	15	7.5	3.5	3.8	26.0	4,761	4,385	376	0.3	24,000+	5,568
Mar.	434	2	0.02	0.0	7	7.5	3.2	5.0	34.2	11,718	7,500	4,218	1.8	13,200	5,729
Apr.	3,130	5, 4*	0.01	2.7	282	7.7	5.2	10.5	77.4	177,471	87,890	89,581	5.3	8,750	27,388
May	917	5	Trace	17.	80	8.4	2.8	7.6	78.	37,634	13,865	23,769	4.8	189,866	174,107
June	692	3	0.015	21.5	120	8.1	2.3	5.6	62.8	20,926	8,595	12,331	3.3	39,966	27,656
Aug.	121	1	0.02	19	90	7.7	3.9	3.1	33.2	2,026	2,548	— 522	— 0.8	210	25
Sept.	218	3	0.01+	17	153	8.2	3.5	5.6	57.1	6,592	4,120	2,472	2.1	350,200	76,344
Oct.	334	4	0.01—	8	32	7.8	7.6	6.5	54.6	11,723	13,707	— 1,981	— 1.1	893,250	298,345
Nov.	330	4	Trace	1.5	42	8.0	12.8	9.5	67.6	16,929	22,810	— 5,881	— 3.3	347,500	114,675
Dec.	297	2	Trace	0.0	60	7.7	12.7	7.3	49.9	11,708	20,368	— 8,660	— 5.4	3,600	1,069
1940															
Jan.	171	2	0.03	0.0	..	...	9.5	7.3	49.9	6,741	8,772	— 2,031	— 2.2	.....	.....
Feb.	184	1	....	0.0	..	...	2.0	6.8	46.5	6,756	1,987	4,769	4.8	.....	.....
Mar.	230	...	....	...	..	...	...	...	...	.....	.....	.....	....	.....	.....
SEASONAL AVERAGES															
A	275	13	0.019	0.0	11	7.6	5.2	3.8	25.8	5,948	7,010	— 1,062	— 1.4	16,589	4,360
B	1,580	13	0.009	13.7	161	8.07	3.43	7.90	72.67	78,677	36,783	41,894	4.47	79,527	76,384
C	170	4	0.015	18	121	7.95	3.7	4.35	45.1	4,309	3,334	975	0.65	175,205	38,184

*Number of B. O. D. samples when the number of D. O. samples is greater than number of B. O. D. samples.

BASE DATA—Table XXI—4

Station	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10) Daily Average Pounds per Day	(11)	(12) Oxygen Balance	(13)	(14) Coliform Organisms	(15)
4	Ave. Daily Flow C.F.S.	No. of Samples	Ave. NO_2-N P.P.M.	Ave. Temp. °C.	Ave. Turb. P.P.M.	Ave. pH	Ave. BOD 20° 5 Day P.P.M.	Dissolved Oxygen P.P.M.	Dissolved Oxygen % Sat.	D.O.	B.O.D.	Pounds (10)-(11)	P.P.M. (8)-(7)	M.P.N. per 100 cc.	M.P.N. Quant. Units
1938															
Nov.	192	7, 3*	0.00	2.07	45	7.9	12.0	4.11	29.7	4,261	12,442	— 8,181	— 7.89	24,000	4,608
Dec.	197	4	0.00	0.0	20	7.6	9.0	0.2	1.4	213	9,574	— 9,361	— 8.8	18,600	3,664
1939															
Jan.	231	4	0.03	0.0	12	7.6	8.7	1.5	10.3	1,871	10,852	— 8,981	— 7.2	7,800	1,802
Feb.	234	3	0.02	0.0	8	7.6	1.9	2.6	17.8	3,285	2,401	884	0.7	3,376.6	790
Mar.	346	3	0.013	0.0	5	7.6	2.7	3.3	22.6	6,166	5,045	1,121	0.6	2,483.3	859
Apr.	3,170	4	0.01+	2.7	340	7.7	6.1	10.0	73.7	171,180	104,420	66,760	3.9	5,407.5	17,142
May	951	6	0.006	16.8	81	8.3	3.3	7.7	78.7	39,543	16,947	22,596	4.4	8,926	8,489
June	696	4	0.023	21.5	107	8.0	2.6	5.4	60.6	20,295	9,772	10,523	2.8	6,882.5	47,902
Aug.	123	1	0.00	22.	100	7.7	4.6	6.1	69.1	4,052	3,055	997	1.5	150	18
Sept.	211	3	0.01+	16.	270	8.3	3.8	7.1	71.3	8,090	4,330	3,760	3.3	3,910	825
Oct.	333	4	0.01—	6.8	62	7.8	6.4	6.7	54.8	12,048	11,508	540	0.3	460,000	153,180
Nov.	329	4	0.01—	1.8	45	8.0	9.5	9.0	64.6	15,989	16,875	— 886	— 0.5	1,313,333	432,087
Dec.	301	2	Trace	0.0	25	7.7	16.1	4.5	30.8	7,314	26,169	18,855	—11.6	Ind.	.....
1940															
Jan.	173	2	0.02	0.0	..	...	6.9	1.9	13.0	1,775	6,446	— 4,671	— 5.0	.....	.....
Feb.	184	1	.....	0.0	..	...	2.0	4.5	30.8	4,471	1,987	2,484	2.5	.....	.....
Mar.	225	1	....	0.0	..	...	4.2	5.4	36.9	6,561	5,103	1,458	1.2	.....	.....
SEASONAL AVERAGES															
A	252	14	0.016	0.0	11	7.6	5.6	1.9	13.0	2,884	6,968	— 4,084	— 3.7	8,065	1,779
B	1,606	14	0.013	13.7	176	8.0	4.0	7.70	71.0	77,006	43,713	33,293	3.7	27,719	24,511
C	167	4	0.006	19	185	8.0	4.2	6.6	70.2	6,071	3,692	2,379	2.4	2,030	421

*Number of B.O.D. samples when the number of D.O. samples is greater than the number of B.O.D. samples.

BASE DATA—Table XXI—3

Station 3	(1) Ave. Daily Flow C.F.S.	(2) No. of Samples	(3) Ave. NO_2-N P.P.M.	(4) Ave. Temp. °C.	(5) Ave. Turb. P.P.M.	(6) Ave. pH	(7) Ave. BOD 20° 5 Day P.P.M.	(8) Dissolved Oxygen P.P.M.	(9) Dissolved Oxygen % Sat.	(10) Daily Average Pounds per Day D.O.	(11) Daily Average Pounds per Day B.O.D.	(12) Oxygen Balance Pounds (10)-(11)	(13) Oxygen Balance P.P.M. (8)-(7)	(14) Coliform Organisms M.P.N. per 100 cc.	(15) Coliform Organisms M.P.N. Quant. Units
1938															
Nov.	189	6, 3*	0.00	1.1	70	7.9	5.4	7.3	51.5	7,450	5,511	1,939	1.9	8,620	1,629
Dec.	200	4	0.00	0.0	25	7.8	9.2	0.0	0.0	0.0	9,936	— 9,936.0	— 9.2	13,257	2,651
1939															
Jan.	219	4	0.01	0.0	12	7.6	8.1	0.7	4.8	828	9,579	— 8,751	— 7.4	2,735	599
Feb.	243	1	0.02	0.0	15	7.5	1.9	0.8	5.5	1,050	2,493	— 1,443	— 1.1	240	58
Mar.	378	3	0.02+	0.0	6	7.5	1.8	1.4	9.6	2,858	3,674	— 816	— 0.4	240	91
Apr.	3,450	4	0.01—	3.0	377	7.9	6.2	9.0	66.8	167,670	115,506	52,164	2.8	4,840	16,698
May	992	4	0.00	15.5	85	8.4	3.8	9.8	97.6	52,497	20,356	32,141	6.0	827.5	821
June	682	5	0.016	21.5	23	8.4	2.6	8.8	98.7	32,409	9,575	22,834	6.2	113.8	78
Aug.	144	1	0.00	19.	15	8.3	2.0	8.0	85.6	6,221	1,555	4,666	6.0	240.	35
Sept.	216	3	0.01+	1.6	135	8.4	2.4	7.8	78.4	9,098	2,799	6,299	5.4	273.3	59
Oct.	344	4	0.01—	6.6	55	8.25	2.6	10.5	85.5	19,505	4,830	14,675	7.9	6,940	3,387
Nov.	334	4	0.01—	0.5	57	8.2	5.4	11.0	76.2	19,840	9,739	10,101	5.6	4,232.5	1,414
Dec.	292	2	Trace	0.0	20	7.7	6.3	3.3	22.6	5,203	9,934	— 4,731	— 3.0	930	272
1940															
Jan.	163	2	0.00	0.0	..	...	8.4	0.3	2.0	264	7,394	— 7,130	— 8.1	.....	.....
Feb.	178	1	....	0.0	..	...	2.5	0.85	5.8	817	2,403	— 1,586	— 1.65	.....	.....
Mar.	225	...	....	...	..	...	...	...	...	.....	.....	.....	....	.....	..
SEASONAL AVERAGES															
A	260	12	0.012	0.0	14	7.6	5.25	0.72	4.92	1,184	6,420	— 5,236	— 4.2	4,118	850
B	1,708	13	0.009	13.3	162	8.23	4.2	9.2	87.7	84,192	48,479	35,713	5.0	1,927	5,866
C	180	4	0.006	17.5	75	8.35	2.20	7.9	82.0	7,659	2,177	5,482	5.70	257	47

*Number of B.O.D. samples when the number of D.O. samples is greater than the number of B.O.D. samples.

BASE DATA—Table XXI—2

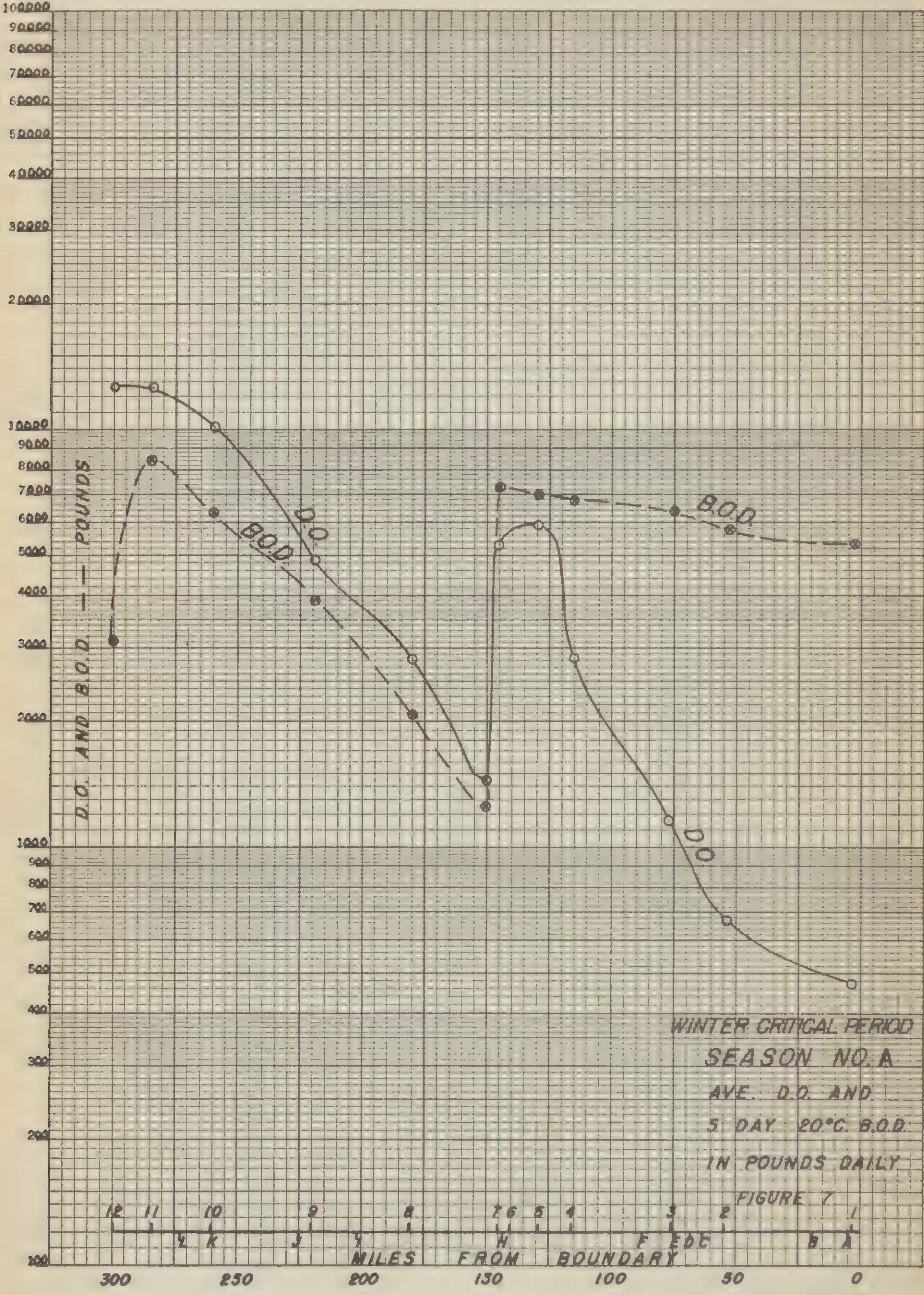
Station 2	(1) Ave. Daily Flow c.f.s.	(2) No. of Samples	(3) Ave. NO_2-N P.P.M.	(4) Ave. Temp. °C.	(5) Ave. Turb. P.P.M.	(6) Ave. pH	(7) Ave. BOD 20° 5 Day P.P.M.	(8) Dissolved Oxygen P.P.M.	(9) Dissolved Oxygen % Sat.	(10) Daily Average Pounds per Day: D.O.	(11) Daily Average Pounds per Day: B.O.D.	(12) Oxygen Balance: Pounds (10)-(11)	(13) Oxygen Balance: P.P.M. (8)-(7)	(14) Coliform Organisms: M.P.N. per 100 cc.	(15) Coliform Organisms: M.P.N. Quant. Units
1938															
Nov.	199	6, 3*	0.00	0.9	60	8.0	2.4	9.1	63.8	9,779	2,597	7,200	6.7	461	92
Dec.	197	4	0.00	0.0	24	7.75	8.6	0.0	0.0	0.0	9,149	— 9,149	—8.6	17,500	3,448
1939															
Jan.	216	4	0.007	0.0	22	7.5	8.2	0.0	0.0	0.0	9,564	— 9,564	—8.2	5,577.5	1,205
Feb.	246	3	0.025	0.0	10	7.5	2.0	0.7	4.8	930	2,657	— 1,727	—1.3	80.1	20
Mar.	302	4	0.01+	0.0	6	7.5	1.5	1.1	7.5	1,794	2,446	— 652	—0.4	299	90
Apr.	3,710	4	0.01—	3.25	410	7.9	5.9	9.0	67.1	180,306	118,201	62,105	3.1	1,461	5,420
May	1,040	4	0.00	14.9	110	8.45	3.6	9.7	95.5	54,475	20,218	34,257	6.1	182	189
June	681	5	0.016	21.	50	8.5	1.4	9.0	100.1	33,097	5,148	27,849	7.6	136.4	93
Aug.	157	1	0.00	19.	60	8.4	3.2	7.3	78.1	6,189	2,713	3,476	4.1	240	38
Sept.	212	3	0.00	16.	167	8.4	2.7	7.9	79.4	9,044	3,091	5,953	5.2	473.3	100
Oct.	337	4	0.01—	5.25	67	8.4	2.3	11.2	87.9	20,382	4,186	16,196	8.9	548.2	185
Nov.	340	4	Trace	0.5	86	8.2	5.5	11.8	81.7	21,665	10,098	11,567	6.3	3,068	1,043
Dec.	297	2	Trace	0.0	50	7.8	4.5	5.5	37.6	8,821	7,217	1,604	1.0	330	98
1940															
Jan.	161	2	0.00	0.0	..	...	7.8	.3	2.0	261	6,681	— 6,520	—7.5	.....	.....
Feb.	175	1	....	0.0	..	...	1.5	1.1	7.5	1,040	1,418	— 378	—0.4	.....	.....
Mar.	218	1	....	0.0	..	...	1.2	1.2	8.2	1,413	1,413	0.000	0.0	.....	.....
SEASONAL AVERAGES															
A	240	15	0.01	0.0	15	7.56	5.06	0.45	3.08	681	5,954	— 5,273	—4.61	5,864	1,191
B	1,810	13	0.009	13.05	190	8.28	3.63	9.23	87.6	89,293	47,856	41,437	5.6	593	1,901
C	184	4	0.00	17.5	113	8.4	2.95	7.6	78.75	7,616	2,902	4,714	4.65	357	69

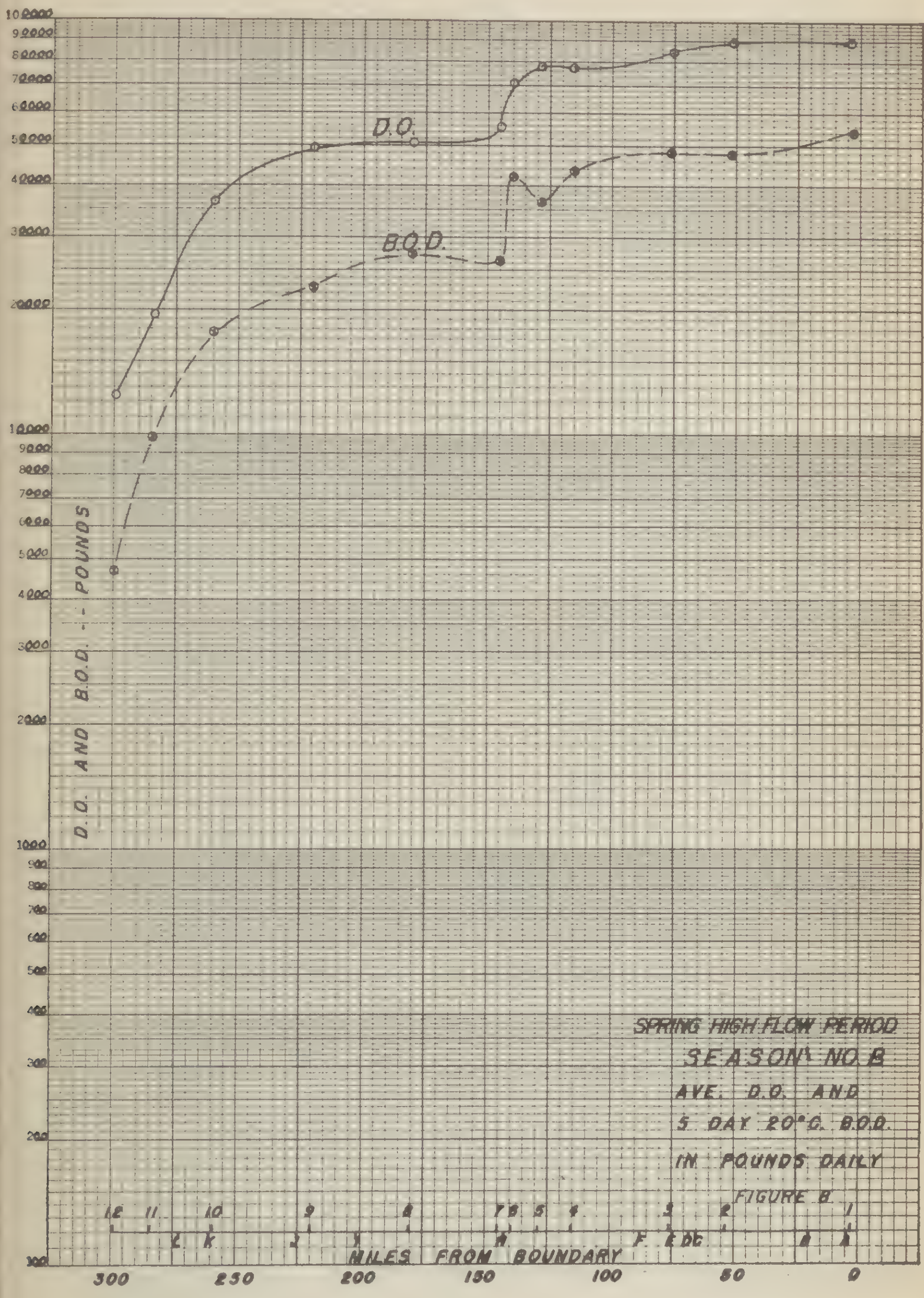
*Number of B.O.D. samples when the number of D.O. samples is greater than the number of B.O.D. samples.

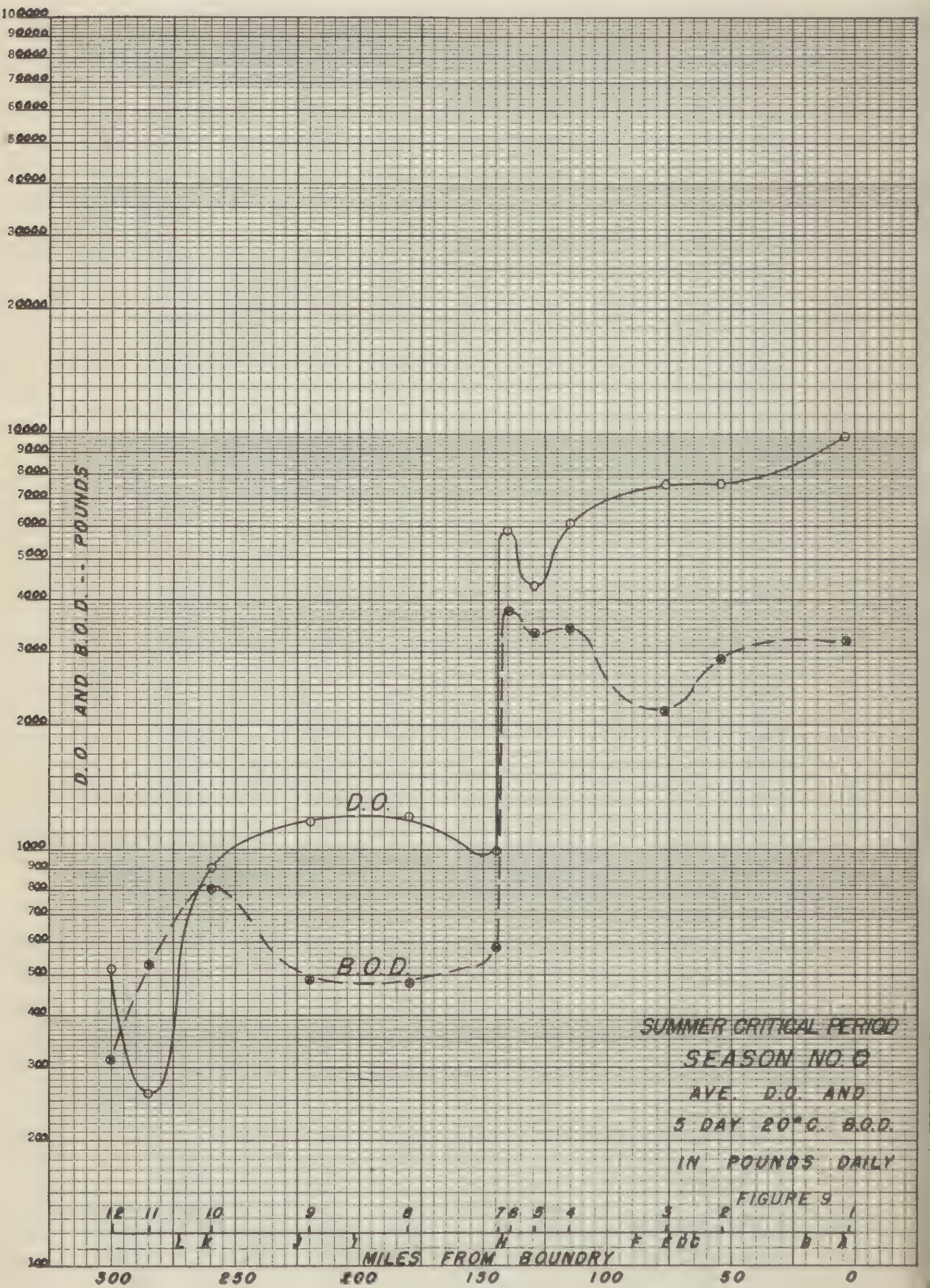
BASE DATA—Table XXI—1

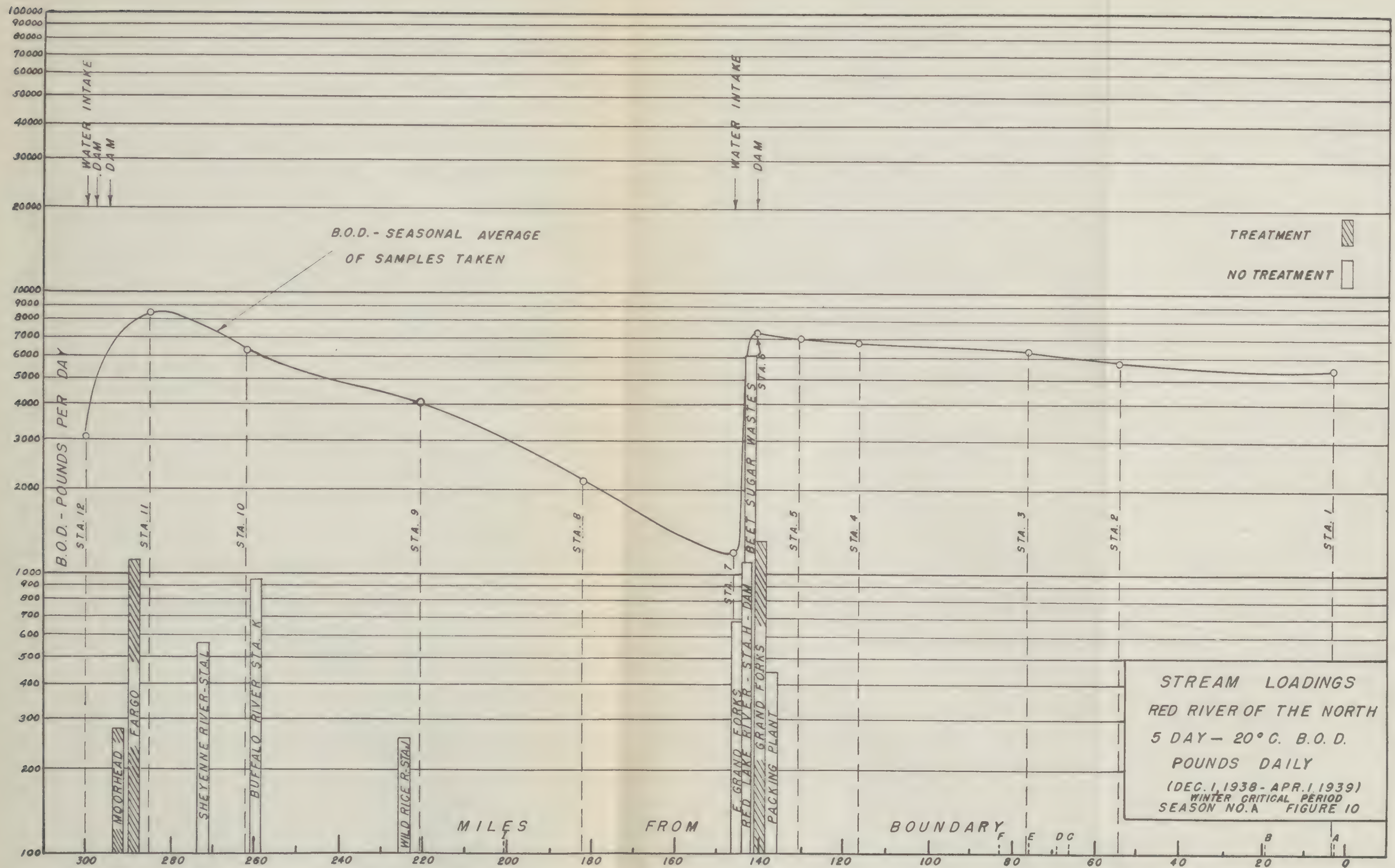
Station	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10) Daily Average Pounds per Day	(11)	(12) Oxygen Balance	(13)	(14) Coliform Organisms	(15)
1	Ave. Daily Flow C.F.S.	No. of Samples	Ave. NO_2-N P.P.M.	Ave. Temp. °C.	Ave. Turb. P.P.M.	Ave. pH	Ave. BOD 20° 5 Day P.P.M.	Dissolved Oxygen P.P.M.	Dissolved Oxygen % Sat.	D.O.	B.O.D.	Pounds (10)-(11)	P.P.M. (8)-(7)	M.P.N. per 100 cc.*	M.P.N. Quant. Units
1938															
Nov.	207	6, 3*	0.00	0.75	45	8.2	2.4	12.66	88.2	14,151	2,683	11,468	10.26	12.7	3
Dec.	182	4	0.00	0.0	26	7.7	7.7	0.4	2.73	393	7,568	— 7,175	7.3	3,866	104
1939															
Jan.	198	4	0.00	0.0	21	7.6	9.1	0.0	0.0	0.0	9,730	— 9,730	— 9.1	12,726	2,520
Feb.	255	2	0.02	0.0	10	7.6	1.6	0.0	0.0	0.0	2,203	— 2,203	— 1.6	84	21
Mar.	260	4	0.01+	0.0	7	7.6	1.7	1.1	7.5	1,544	2,387	— 843	—0.6	35	9
Apr.	3,690	4	Trace	2.8	470	7.8	6.9	9.1	67.2	181,327	137,489	181,327	2.2	5,025	18,542
May	1,180	4	0.00	14.75	187	8.35	3.1	9.2	90.0	58,622	19,753	38,869	6.1	120.5	142
June	646	5	0.02	19.5	124	8.5	1.7	8.0	86.4	27,907	5,930	21,977	6.3	153.2	99
Aug.	188	1	0.00	19.	70	8.5	3.8	8.6	92.0	8,731	3,858	4,873	4.8	93	17
Sept.	230	3	0.00	16.	140	8.4	2.1	8.8	89.4	10,930	2,608	8,322	6.7	317.7	73
Oct.	338	4	0.01	5.68	82	8.3	2.1	11.0	87.4	20,077	3,833	16,244	8.9	505	171
Nov.	391	4	Trace	1.25	72	8.3	3.8	12.2	86.2	25,759	8,023	17,736	8.4	8,750	3,421
Dec.	284	2	Trace	0.00	50	8.0	2.9	9.6	65.7	14,723	4,447	10,276	6.7	109.5	31
1940															
Jan.	139	2	0.00	0.00	..	...	4.0	1.2	8.2	901	3,002	— 2,101	—2.8	.....	....
Feb.	149	1	....	0.00	..	...	1.9	.2	1.4	161	1,529	— 1,368	1.7	.....	.....
Mar.	225	1	....	0.00	..	...	1.7	.6	4.1	729	2,066	— 1,337	—1.1	.....	.....
SEASONAL AVERAGES															
A	226	14	0.008	0.0	16	7.62	5.02	0.38	2.56	484	5,472	— 4,988	4.64	4,178	663
B	1,839	13	0.008	12.35	260	8.22	3.9	8.77	81.2	89,285	54,391	34,894	4.87	1,766	6,261
C	209	4	0.00	17.5	105	8.45	2.95	8.7	90.7	9,830	3,233	6,597	5.75	205	45

*Number of B.O.D. samples when the number of D.O. samples is greater than the number of B.O.D. samples.

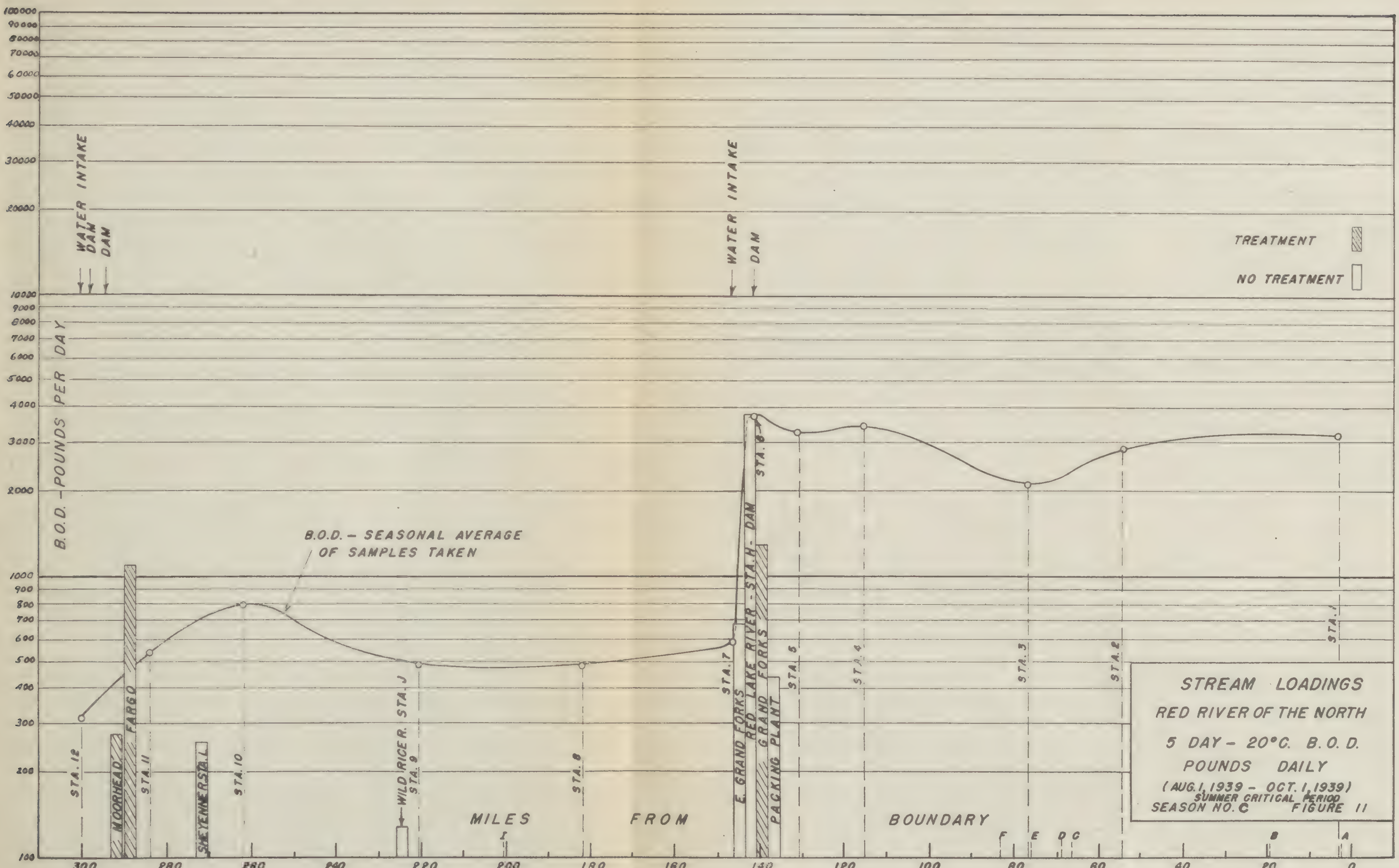

D.O. AND B.O.D. — POUNDS
D.O.
B.O.D.
WINTER CRITICAL PERIOD
SEASON NO. A
AVE. D.O. AND
5 DAY 20°C. B.O.D.
IN POUNDS DAILY
FIGURE 7
MILES FROM BOUNDARY
300
250
200
150
100
50
0


D.O.
B.O.D.
D.O. AND B.O.D. - POUNDS
MILES FROM BOUNDARY
300
250
200
150
100
50
0
SPRING HIGH FLOW PERIOD
SEASON NO. B
AVE. D.O. AND
5 DAY 20°C. B.O.D.
IN POUNDS DAILY
FIGURE 8.

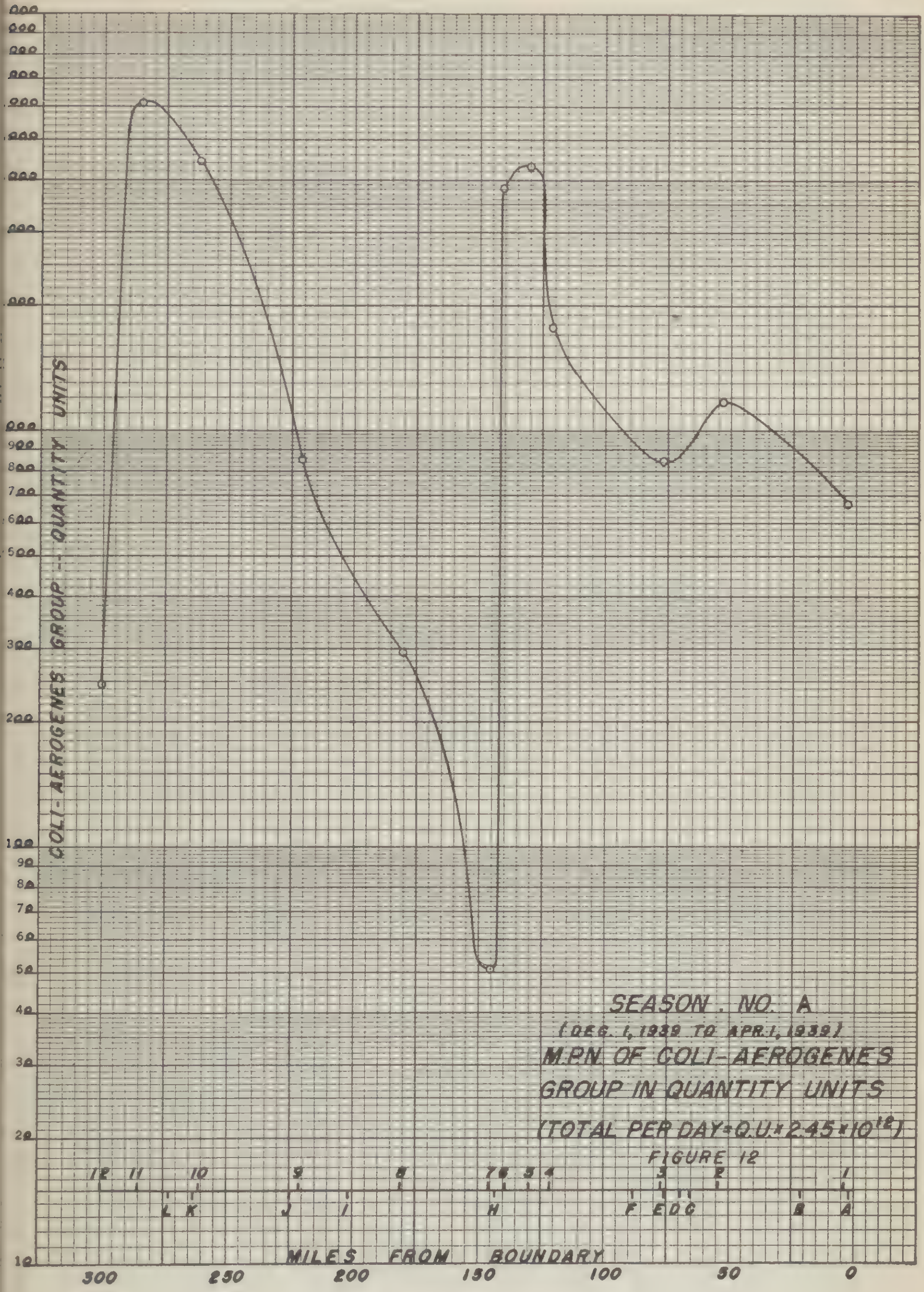

D.O. AND B.O.D. -- POUNDS
D.O.
B.O.D.
SUMMER CRITICAL PERIOD
SEASON NO. 6
AVE. D.O. AND
5 DAY 20° C. B.O.D.
IN POUNDS DAILY
FIGURE 9
MILES FROM BOUNDRY
300
250
200
150
100
50
0

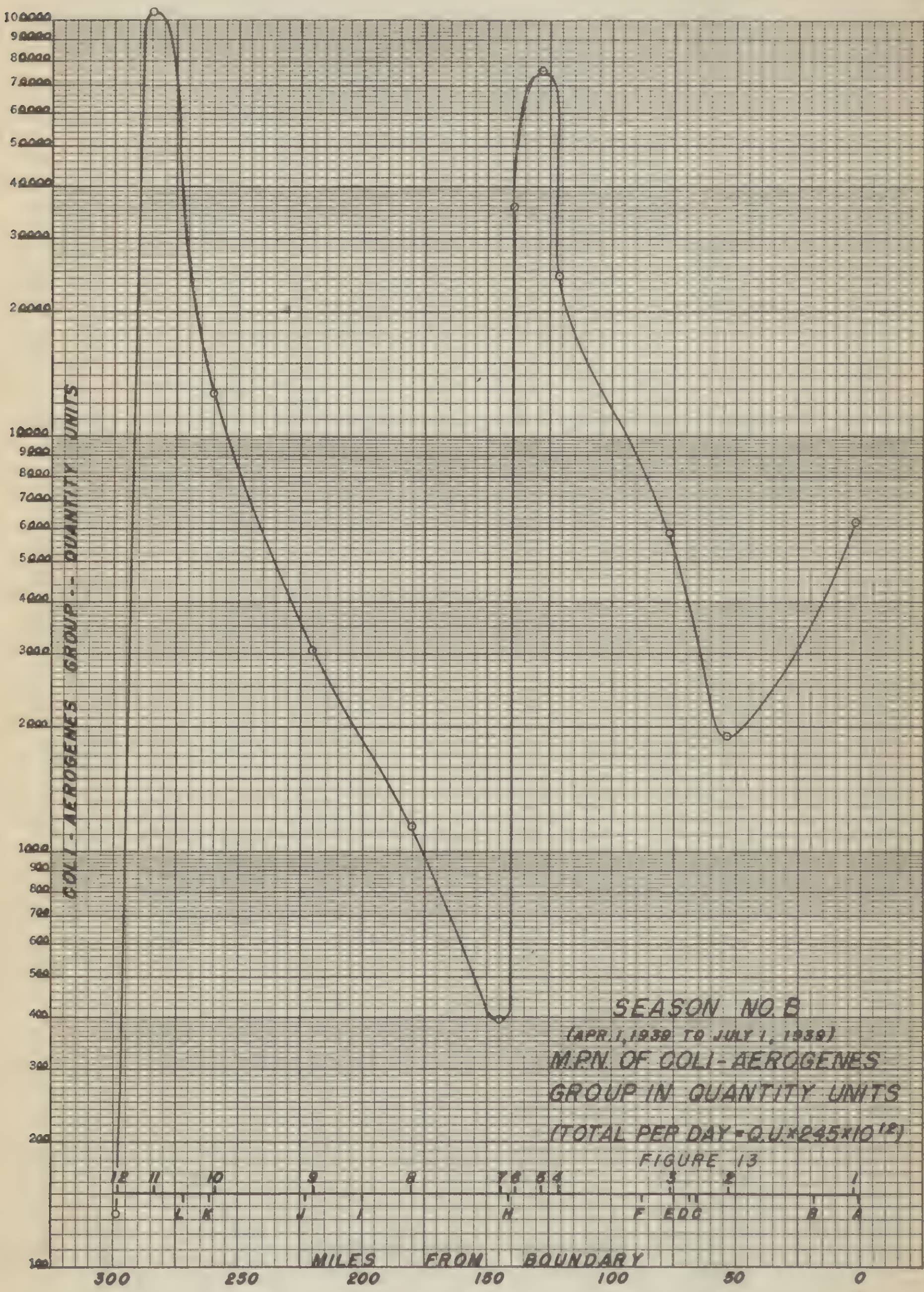


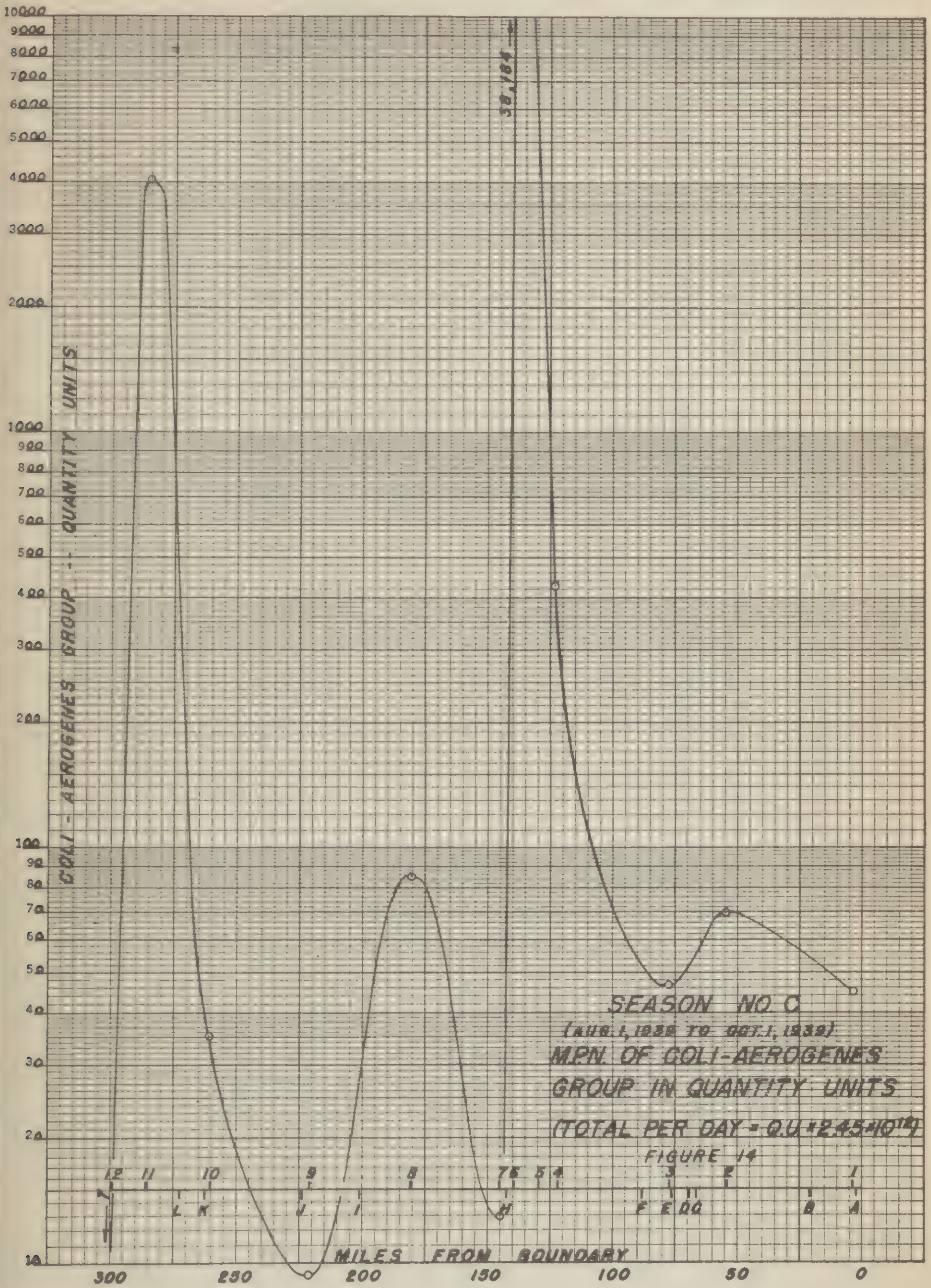
STREAM LOADINGS
RED RIVER OF THE NORTH
5 DAY — 20° C. B.O.D.
POUNDS DAILY
(DEC. 1, 1938 - APR. 1 1939)
WINTER CRITICAL PERIOD
SEASON NO. A FIGURE 10
B.O.D. - SEASONAL AVERAGE OF SAMPLES TAKEN
TREATMENT
NO TREATMENT
B.O.D. - POUNDS PER DAY
MILES FROM BOUNDARY
WATER INTAKE
DAM
DAM
WATER INTAKE
DAM
STA. 12
STA. 11
STA. 10
STA. 9
STA. 8
STA. 7
STA. 6
STA. 5
STA. 4
STA. 3
STA. 2
STA. 1
MOORHEAD
FARGO
SHEYENNE RIVER-STA. L
BUFFALO RIVER STA. K
WILD RICE R.-STA. J
E. GRAND FORKS
RED LAKE RIVER - STA. H - DAM
BEET SUGAR WASTES
GRAND FORKS
PACKING PLANT
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
F
E
D
C
B
A



STREAM LOADINGS
RED RIVER OF THE NORTH
5 DAY - 20°C. B.O.D.
POUNDS DAILY
(AUG. 1, 1939 - OCT. 1, 1939)
SUMMER CRITICAL PERIOD
SEASON NO. C
FIGURE 11


COLI-AEROGENES GROUP -- QUANTITY UNITS
SEASON . NO. A
(DEC. 1, 1938 TO APR. 1, 1939)
M.P.N. OF COLI-AEROGENES
GROUP IN QUANTITY UNITS
(TOTAL PER DAY = Q.U. × 2.45 × 10^12)
FIGURE 12
MILES FROM BOUNDARY
300
250
200
150
100
50
0


SEASON NO. B
(APR. 1, 1939 TO JULY 1, 1939)
M.P.N. OF COLI-AEROGENES
GROUP IN QUANTITY UNITS
(TOTAL PER DAY = Q.U.×245×10¹²)
FIGURE 13
COLI-AEROGENES GROUP -- QUANTITY UNITS
MILES FROM BOUNDARY
300
250
200
150
100
50
0
12 11 10 9 8 7 6 5 4 3 2 1
L K J I H F E D C B A


COLI - AEROGENES GROUP -- QUANTITY UNITS
38,784
SEASON NO. C
M.P.N. OF COLI-AEROGENES
GROUP IN QUANTITY UNITS
FIGURE 14
MILES FROM BOUNDARY
300
250
200
150
100
50
0

BASE DATA—Table XXII—L

Station	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10) Daily Average Pounds per Day	(11)	(12) Oxygen Balance	(13)	(14) Coliform Organisms	(15)
L	Ave. Daily Flow C.F.S.	No. of Samples	Ave. NO_2-N P.P.M.	Ave. Temp. °C.	Ave. Turb. P.P.M.	Ave. pH	Ave. BOD 20° 5 Day P.P.M.	Dissolved Oxygen P.P.M.	Dissolved Oxygen % Sat.	D.O.	B.O.D.	Pounds (10)-(11)	P.P.M. (8)-(7)	M.P.N. per 100 cc.	M.P.N. Quant. Units
1938															
Nov.	15	5	0.021	2	17	8.1—	2.89	11.4	82.7	923	234	789	8.51	955	14
Dec.	12	4	0.01	0.0	15	7.7	1.58	7.6	52.0	492	102	390	6.02	17,600	211
1939															
Jan.	11	4	Trace	0.0	11	7.5+	2.15	5.3	36.2	315	182	187	3.15	1,907	21
Feb.	10	4	0.005	0.0	11	7.55	3.08	3.7	25.3	200	166	34	.62	3,422	34
Mar.	96	5	0.012	0.0	58	7.5	3.74	4.0	27.3	2,074	1,939	135	.26	5,108	490
Apr.	265	4	0.005	3+	143	7.8	5.88	11.7	79.4	16,742	8,414	8,328	5.82	8,210	2,176
May	64	4	0.00	14+	62	8.35	3.25	9.0	86.8	3,110	1,123	1,987	5.75	875	56
June	55	4	0.01	20—	65	8.3	4.68	8.2	89.4	2,435	1,390	1,045	3.52	3,606	198
Aug.	11	1	0.10	20	100	8.4	5.86	6.9	75.2	410	348	62	1.04	430	5
Sept.	9	3	0.06	17+	70	8.4	3.74	6.6	67.8	320	181	139	2.86	1,177	11
Oct.	13	4	0.255	8+	31	8.05	5.47	8.2	69.1	576	384	192	2.73	1,320	17
Nov.	17	5	0.03	1+	16	8.4	4.15	11.6	81.4	1,065	381	684	7.45	5,681	97
Dec.	18	1	0.02	2	20	8.4	2.42	11.4	82.3	1,108	235	873	8.98	1,500	11
1940															
Jan.	7	...	0.01	0.0	..	7.6	1.94	...	...	.....	73	.....	....	.....	.....
Feb.	8	...	....	0.0	..	...	...	...	...	.....	.....	.....	....	.....	.....
Mar.	7	...	....	...	..	...	...	...	...	.....	.....	.....	....	.....	.....
SEASONAL AVERAGES															
A	...	17	0.007	0.0	24	7.56	2.66	5.15	35.20	770	584	186	+2.49	7,009	189
B	...	12	0.005	12.3	90	8.15	4.60	9.30	85.20	7,429	3,642	3,787	+4.70	4,230	810
C	...	4	0.08	18.5	85	8.4	4.80	6.75	71.50	365	265	100	+1.95	1,248	8

BASE DATA—Table XXII—K

Station	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10) Daily Average Pounds per Day	(11)	(12) Oxygen Balance	(13)	(14) Coliform Organisms	(15)
K	Ave. Daily Flow c.f.s.	No. of Samples	Ave. NO_2-N P.P.M.	Ave. Temp. °C.	Ave. Turb. P.P.M.	Ave. pH	Ave. BOD 20° 5 Day P.P.M.	Dissolved Oxygen P.P.M.	Dissolved Oxygen % Sat.	D.O.	B.O.D.	Pounds (10)-(11)	P.P.M. (8)-(7)	M.P.N. per 100 cc.	M.P.N. Quant. Units
1938															
Nov.	11	5	0.00	1	13	8.0+	2.75	9.1	65.7	541	163	378	6.35	109	1
Dec.	8	4	0.005	0.0	16	7.65	1.00	0.3	2.0	13	43	— 30	— .70	199	2
1939															
Jan.	6	4	0.00	0.0	35	7.4	4.38	0	0.0	0	142	— 142	—4.38	275	2
Feb.	4	4	0.00	0.0	22	7.5—	4.72	0	0.0	0	102	— 102	—4.72	1,032.5	4
Mar.	163	5	0.004	0.0	37	7.4—	4.05	1.4	9.6	1,232	3,565	— 2,333	—2.65	2,782.6	454
Apr.	318	4	0.01	4—	97	7.8+	4.11	11.1	84.4	19,060	7,057	12,003	6.99	325	103
May	37	4	0.00	14	20	8.4+	1.73	8.7	83.8	1,738	346	1,392	6.97	240	9
June	19	4	0.00	19	16	8.4+	1.54	7.3	78.1	749	158	591	5.76	448	9
Aug.	2	1	0.00	19	90	8.5	1.63	7.9	84.4	85	18	67	6.27	200	0.4
Sept.	2	3	0.00	16+	40	8.5—	2.69	7.5	75.4	81	29	52	4.81	4,060	8
Oct.	5	4	Trace	8+	32	7.95	6.71	6.7	57.0	181	181	00	— .01	2,725	14
Nov.	8	5	0.00	2—	25	8.2	1.92	11.0	79.4	475	83	392	9.08	840	7
Dec.	9	1	0.00	0.0	30	8.0	1.25	8.4	57.4	408	61	347	7.15	73	0.7
1940															
Jan.	2	...	0.01	0.0	..	7.7	1.17	...	...	.....	13	.....	....	.....	.....
Feb.	1	...	....	0.0	..	...	...	...	...	.....	.....	.....	....	.....	.....
Mar.	3	...	....	...	..	...	...	...	...	.....	.....	.....	....	.....	.....
SEASONAL AVERAGES															
A	...	17	0.002	0.0	27.5	7.49	1.04	0.42	2.90	311	963	— 652	—0.62	1,072	141
B	...	12	0.003	12.3	44	8.20	2.46	9.03	82.10	7,182	2,520	4,662	+6.57	338	40
C	...	4	0.00	17.5	65	8.5	2.16	7.7	79.90	83	24	59	+5.54	2,130	4.2

BASE DATA—Table XXII—J

Station J	(1) Ave. Daily Flow C.F.S.	(2) No. of Samples	(3) Ave. NO_2-N P.P.M.	(4) Ave. Temp. °C.	(5) Ave. Turb. P.P.M.	(6) Ave. pH	(7) Ave. BOD 20° 5 Day P.P.M.	(8) Dissolved Oxygen P.P.M.	(9) Dissolved Oxygen % Sat.	(10) Daily Average Pounds per Day D.O.	(11) Daily Average Pounds per Day B.O.D.	(12) Oxygen Balance Pounds (10)-(11)	(13) Oxygen Balance P.P.M. (8)-(7)	(14) Coliform Organisms M.P.N. per 100 cc.	(15) Coliform Organisms M.P.N. Quant. Units
1938															
Nov.	17	5	0.00	1+	17	8.1	2.15	11.6	81.4	1,065	197	868	9.45	421	7
Dec.	21	4	0.00	0.0	10	7.8—	1.00	7.0	47.8	793	113	680	6.00	321.5	7
1939															
Jan.	18	4	0.015	0.0	12	7.5	0.72	2.1	14.4	204	70	134	1.38	76	1
Feb.	18	4	0.005	0.0	11	7.5—	1.80	1.7	11.6	165	175	— 10	— .10	305.5	5
Mar.	48	5	Trace	0.0	18	7.5	2.67	3.2	21.9	829	692	137	0.53	372.6	18
Apr.	262	4	Trace	3	106	7.9+	2.86	11.5	85.4	16,270	4,046	12,224	8.64	214	56
May	100	4	0.00	14+	75	8.4	1.41	8.4	77.3	4,536	761	3,775	6.99	1,386	14
June	72	4	0.002	20	64	8.4	1.59	7.7	84.0	2,994	618	5,376	6.11	1,858	134
Aug.	16	1	0.00	18	70	8.5	1.20	7.5	78.6	648	103	545	6.30	200	3
Sept.	14	3	0.00	21	63	8.4+	1.95	7.3	81.2	552	147	405	5.35	1,263	18
Oct.	16	4	0.00	16+	40	8.0	4.63	8.3	83.5	717	400	317	3.67	242.5	4
Nov.	17	5	0.005	8+	20	8.2+	1.45	11.8	99.4	1,083	133	950	10.35	144.4	2
Dec.	20	1	0.00	2—	15	8.2	1.58	8.7	62.8	940	171	769	7.12	91	2
1940															
Jan.	9	...	0.00	0.0	..	7.7	2.08	4.4	30.1	214	101	113	2.32	.....	.....
Feb.	7	...	....	0.0	..	...	1.73	...	...	.....	65	.....	....	.....	.....
Mar.	11	...	....	...	..	...	...	...	...	.....	.....	.....	....	.....	.....
SEASONAL AVERAGES															
A	...	17	0.005	0.0	13	7.57	1.55	3.50	23.92	498	263	235	+1.95	269	7.8
B	...	12	Trace	12.3	82	8.23	1.95	9.20	82.23	7,900	1,808	6,125	+7.25	1,153	68.0
C	...	4	0.00	19.5	66	8.45	1.57	7.4	79.90	600	125	475	+5.83	731	10.5

BASE DATA—Table XXII—H

Station H	(1) Ave. Daily Flow C.F.S.	(2) No. of Samples	(3) Ave. NO_2-N P.P.M.	(4) Ave. Temp. °C.	(5) Ave. Turb. P.P.M.	(6) Ave. pH	(7) Ave. BOD 20° 5 Day P.P.M.	(8) Dissolved Oxygen P.P.M.	(9) Dissolved Oxygen % Sat.	(10) Daily Average Pounds per Day: D.O.	(11) Daily Average Pounds per Day: B.O.D.	(12) Oxygen Balance: Pounds (10)-(11)	(13) Oxygen Balance: P.P.M. (8)-(7)	(14) Coliform Organisms: M.P.N. per 100 cc.	(15) Coliform Organisms: M.P.N. Quant. Units
1938															
Nov.	131	3	0.00	1	5	8.3+	2.77	12.5	87.8	8,843	1,560	7,283	9.73	261	34
Dec.	141	4	0.01	0.0	12	7.75	1.82	7.6	52.0	5,787	1,386	4,401	5.78	20,750	2,926
1939															
Jan.	159	5	0.012	0.0	17	7.6+	1.07	2.9	19.8	2,489	919	1,570	1.83	2,848	453
Feb.	130	4	0.003	0.0	12	7.55	1.35	1.3	8.9	913	948	— 35	— .05	4,775	621
Mar.	181	4	Trace	0.0	15	7.45	1.34	1.2	8.2	1,173	1,310	— 143	— .14	5,550	1,005
Apr.	675	4	Trace	3	62	7.8	2.11	8.5	63.0	30,982	7,691	23,291	6.39	2,266	1,530
May	456	5	0.00	18—	98	8.3—	3.43	7.1	74.4	17,483	8,446	9,037	3.67	286.5	131
June	320	4	0.00	21—	109	8.4—	3.25	6.8	75.7	11,750	5,616	6,134	3.55	195	62
Aug.	80	1	Trace	23	40	8.4	4.20	7.3	84.1	3,154	1,814	1,340	3.10	430	34
Sept.	210	3	Trace	17	47	8.4	5.11	8.1	81.4	9,185	5,795	3,390	2.99	8,151	1,712
Oct.	299	4	0.00	7+	42	8.3—	4.64	9.7	79.7	15,662	7,492	8,170	5.06	15,106	4,517
Nov.	292	4	0.00	2—	20	8.3	5.41	12.7	91.7	20,025	8,530	11,495	7.29	5,765	1,683
Dec.	260	2	....	0.0	60	8.0	1.66	11.4	77.9	16,006	2,331	13,675	9.74	.....	.....
1940															
Jan.	161	2	0.00	0.0	..	8.2	1.44	8.9	60.8	7,738	1,252	6,586	7.46	.....	.....
Feb.	182	1	....	0.0	..	...	...	5.2	35.5	5,111	.....	.....	....	.....	.....
Mar.	160	1	....	0.0	..	...	...	4.7	32.1	4,061	.....	.....	....	.....	.....
SEASONAL AVERAGES															
A	...	17	0.006	0.0	14	7.59	1.39	3.25	22.45	2,590	1,141	1,448	+1.86	8,481	1,251
B	...	13	Trace	14	90	8.16	2.93	7.47	71.3	20,072	7,251	12,754	+4.54	916	574
C	...	4	Trace	19.5	43	8.4	4.65	7.7	82.75	6,169	3,805	2,365	+3.05	4,290	873

OXYGEN REQUIREMENTS UNDER ICE COVERAGE
(Based On Oxygen Demand From The Station Specified To Grand Forks)
November 1938
Table XXIII—1

Station	Flow	Time of Flow to Grand Forks	Five Day 20°C B.O.D.	0°C B.O.D. For Time of Flow to Grand Forks	Oxygen Demand at 0°C for Time of Flow To Grand Forks	Dissolved Oxygen Available	Dissolved Oxygen Available	OXYGEN RELATIONSHIPS: Surplus Over Demand Only	OXYGEN RELATIONSHIPS: Deficit Due to Demand Only	OXYGEN RELATIONSHIPS: Surplus Over Demand Only	OXYGEN RELATIONSHIPS: Deficit Due to Demand Only
	C.F.S.	Days	P.P.M.	P.P.M.	Lbs. Daily	P.P.M.	Lbs. Daily	Lbs. Daily	Lbs. Daily	P.P.M.	P.P.M.
12	23	24.4	4.5	3.83	476	12.0	1,490	1,014	.....	8.17	.....
11	23	22.0	13.1	10.75	1,335	9.3	1,155	180	.....	1.45	.....
10	45	17.0	3.2	2.32	564	10.7	2,600	2,036	.....	8.38	.....
9	62	10.7	1.3	.74	248	11.36	3,803	3,555	.....	10.62	.....
8	62	5.2	1.7	.57	191	12.96	4,339	4,148	.....	12.39	.....
7	59	0.6	3.2	.14	45	13.2	4,205	4,128	.....	13.1	.....

OXYGEN REQUIREMENTS UNDER ICE COVERAGE
(Based On Oxygen Demand From The Station Specified To Grand Forks)
December 1938
Table XXIII—2

Station	Flow	Time of Flow to Grand Forks	Five Day 20°C B.O.D.	0°C B.O.D. For Time of Flow to Grand Forks	Oxygen Demand at 0°C for Time of Flow To Grand Forks	Dissolved Oxygen Available	Dissolved Oxygen Available	OXYGEN RELATIONSHIPS: Surplus Over Demand Only	OXYGEN RELATIONSHIPS: Deficit Due to Demand Only	OXYGEN RELATIONSHIPS: Surplus Over Demand Only	OXYGEN RELATIONSHIPS: Deficit Due to Demand Only
	C.F.S.	Days	P.P.M.	P.P.M.	Lbs. Daily	P.P.M.	Lbs. Daily	Lbs. Daily	Lbs. Daily	P.P.M.	P.P.M.
12	25	25.6	3.3	3.8	378	9.2	1,242	864	.....	6.4	.....
11	25	23.2	12.3	10.2	1,377	6.5	877	.....	500	..	3.7
10	38	18.3	1.6	1.2	246	1.7	349	103	.....	0.5	.....
9	57	11.5	1.7	1.0	308	2.2	677	369	.....	1.2	.....
8	56	5.7	1.4	0.5	151	2.4	726	575	.....	1.9	.....
7	59	0.7	2.7	0.2	64	9.9	3,154	3,090	.....	9.7	.....

OXYGEN REQUIREMENTS UNDER ICE COVERAGE
(Based On Oxygen Demand From The Station Specified To Lake Winnipeg)
December 1938
Table XXIII—3

Station	Flow	Time of Flow to Lake Winnipeg	Five Day 20°C B.O.D.	0°C B.O.D. for Time of Flow to Lake Winnipeg	Oxygen Demand at 0°C for Time of Flow to Lake Winnipeg	Dissolved Oxygen Available	Dissolved Oxygen Available	OXYGEN RELATIONSHIPS			
								Surplus Over Demand Only	Deficit Due to Demand Only	Surplus Over Demand Only	Deficit Due to Demand Only
	C.F.S.	Days	P.P.M.	P.P.M.	Lbs.	P.P.M.	Lbs.	Lbs.	Lbs.	P.P.M.	P.P.M.
6	199	28.8	17.3	15.5	16,656	7.9	8,490	.....	8,166	.....	7.60
5	198	27.6	8.7	8.20	8,767	3.4	3,635	.....	5,132	.....	4.80
4	197	26.4	9.0	7.86	8,361	0.20	213	.....	8,148	.....	7.66
3	200	22.6	9.2	7.64	8,251	0.00	0.00	.....	8,251	.....	7.64
2	197	20.2	8.6	6.84	7,276	0.00	0.00	.....	7,276	.....	6.84
1	182	15.6	7.7	5.43	5,337	0.40	393	.....	4,944	.....	5.03

OXYGEN REQUIREMENTS UNDER ICE COVERAGE
(Based On Oxygen Demand From The Station Specified To Grand Forks)
January 1939
Table XXIII—4

Station	Flow	Time of Flow to Grand Forks	Five Day 20°C B.O.D.	0°C B.O.D. For Time of Flow to Grand Forks	Oxygen Demand at 0°C for Time of Flow To Grand Forks	Dissolved Oxygen Available	Dissolved Oxygen Available	OXYGEN RELATIONSHIPS			
								Surplus Over Demand Only	Deficit Due to Demand Only	Surplus Over Demand Only	Deficit Due to Demand Only
	C.F.S.	Days	P.P.M.	P.P.M.	Lbs. Daily	P.P.M.	Lbs. Daily	Lbs. Daily	Lbs. Daily	P.P.M.	P.P.M.
12	97	18.3	2.2	1.7	890	8.9	4,662	3,772	.....	7.2	.....
11	98	16.9	11.4	8.8	4,657	8.7	4,604	.....	53	.....	0.1
10	95	14.1	2.8	1.9	975	4.2	2,155	1,180	.....	2.3	.....
9	98	9.4	2.0	1.0	529	1.9	1,005	476	.....	0.9	.....
8	85	4.8	2.3	0.7	321	0.5	229	.....	92	.....	0.2
7	78	0.6	2.1	0.1	42	1.1	463	421	.....	1.0	.....

OXYGEN REQUIREMENTS UNDER ICE COVERAGE
(Based On Oxygen Demand From The Station Specified To Lake Winnipeg)
January 1939
Table XXIII—5

Station	Flow	Time of Flow to Lake Winnipeg	Five Day 20°C B.O.D.	0°C B.O.D. for Time of Flow to Lake Winnipeg	Oxygen Demand at 0°C for Time of Flow to Lake Winnipeg	Dissolved Oxygen Available	Dissolved Oxygen Available	OXYGEN RELATIONSHIPS Surplus Over Demand Only	Deficit Due to Demand Only	Surplus Over Demand Only	Deficit Due to Demand Only
	C.F.S.	Days	P.P.M.	P.P.M.	Lbs.	P.P.M.	Lbs.	Lbs.	Lbs.	P.P.M.	P.P.M.
6	237	26.7	2.7	2.36	3,020	3.7	4,739	1,719	.....	1.34	....
5	235	25.6	5.4	4.67	5,926	2.9	3,680	.....	2,246	....	1.77
4	231	24.4	8.7	7.40	9,231	1.5	1,871	.....	7,360	....	5.90
3	219	21.7	8.1	6.62	7,829	0.7	828	.....	7,001	....	5.92
2	216	19.4	8.2	6.48	7,558	0.0	0.0	.....	7,558	....	6.48
1	198	15.3	9.1	6.36	6,800	0.0	0.0	.....	6,800	....	6.36

OXYGEN REQUIREMENTS UNDER ICE COVERAGE
(Based On Oxygen Demand From The Station Specified To Grand Forks)
February 1939
Table XXIII—6

Station	Flow	Time of Flow to Grand Forks	Five Day 20°C B.O.D.	0°C B.O.D. For Time of Flow to Grand Forks	Oxygen Demand at 0°C for Time of Flow To Grand Forks	Dissolved Oxygen Available	Dissolved Oxygen Available	OXYGEN RELATIONSHIPS Surplus Over Demand Only	Deficit Due to Demand Only	Surplus Over Demand Only	Deficit Due to Demand Only
	C.F.S.	Days	P.P.M.	P.P.M.	Lbs. Daily	P.P.M.	Lbs. Daily	Lbs. Daily	Lbs. Daily	P.P.M.	P.P.M.
12	102	17.3	1.7	1.2	661	10.4	5,728	5,067	.....	9.2	....
11	102	16.0	4.8	3.4	1,873	9.8	5,399	3,526	.....	6.4	....
10	102	13.3	3.7	2.4	1,322	6.7	3,690	2,368	.....	4.3	....
9	114	8.7	1.8	0.9	554	3.3	2,031	1,477	.....	2.4	....
8	106	4.4	1.4	0.3	172	1.7	973	801	.....	1.4	....
7	99	.5	1.3	0.1	53	0.9	481	428	.....	0.8	....

OXYGEN REQUIREMENTS UNDER ICE COVERAGE
(Based On Oxygen Demand From The Station Specified To Lake Winnipeg)
February 1939
Table XXIII—7

Station	Flow	Time of Flow to Lake Winnipeg	Five Day 20°C B.O.D.	0°C B.O.D. for Time of Flow to Lake Winnipeg	Oxygen Demand at 0°C for Time of Flow to Lake Winnipeg	Dissolved Oxygen Available	Dissolved Oxygen Available	OXYGEN RELATIONSHIPS			
								Surplus Over Demand Only	Deficit Due to Demand Only	Surplus Over Demand Only	Deficit Due to Demand Only
	C.F.S.	Days	P.P.M.	P.P.M.	Lbs.	P.P.M.	Lbs.	Lbs.	Lbs.	P.P.M.	P.P.M.
6	229	27.0	2.3	2.02	2,498	2.5	3,091	593	.....	.48	....
5	232	25.9	3.5	3.04	3,809	3.8	4,761	952	.....	.76	....
4	234	24.7	1.9	1.62	2,047	2.6	3,285	1,238	.....	.98	....
3	243	20.7	1.9	1.53	2,008	0.8	1,050	.....	958	...	.73
2	246	18.6	2.0	1.53	2,032	0.7	930	.....	1,102	...	.83
1	255	13.7	1.6	1.05	1,446	0.00	0.00	.....	1,446	...	1.05

OXYGEN REQUIREMENTS UNDER ICE COVERAGE
(Based On Oxygen Demand From The Station Specified To Grand Forks)
March 1939
Table XXIII—8

Station	Flow	Time of Flow to Grand Forks	Five Day 20°C B.O.D.	0°C B.O.D. For Time of Flow to Grand Forks	Oxygen Demand at 0°C for Time of Flow To Grand Forks	Dissolved Oxygen Available	Dissolved Oxygen Available	OXYGEN RELATIONSHIPS			
								Surplus Over Demand Only	Deficit Due to Demand Only	Surplus Over Demand Only	Deficit Due to Demand Only
	C.F.S.	Days	P.P.M.	P.P.M.	Lbs. Daily	P.P.M.	Lbs. Daily	Lbs. Daily	Lbs. Daily	P.P.M.	P.P.M.
12	743	6.3	2.5	1.0	4,012	9.7	38,918	34,906	.....	8.7	....
11	743	5.8	5.8	2.1	8,426	9.8	39,320	30,894	.....	7.7	....
10	855	4.8	4.4	1.4	6,464	6.8	31,396	24,932	.....	5.4	....
9	723	3.4	3.4	0.8	3,123	4.1	16,007	12,884	.....	3.3	....
8	626	1.8	1.8	0.2	679	2.8	9,465	8,786	.....	2.6	....
7	274	0.3	1.8	0.1	148	1.1	1,628	1,480	.....	1.0	....

OXYGEN REQUIREMENTS UNDER ICE COVERAGE
(Based On Oxygen Demand From The Station Specified To Lake Winnipeg)
March 1939
Table XXIII—9

Station	Flow	Time of Flow to Lake Winnipeg	Five Day 20°C B.O.D.	0°C B.O.D. for Time of Flow to Lake Winnipeg	Oxygen Demand at 0°C for Time of Flow to Lake Winnipeg	Dissolved Oxygen Available	Dissolved Oxygen Available	OXYGEN RELATIONSHIPS: Surplus Over Demand Only	OXYGEN RELATIONSHIPS: Deficit Due to Demand Only	OXYGEN RELATIONSHIPS: Surplus Over Demand Only	OXYGEN RELATIONSHIPS: Deficit Due to Demand Only
	C.F.S.	Days	P.P.M.	P.P.M.	Lbs.	P.P.M.	Lbs.	Lbs.	Lbs.	P.P.M.	P.P.M.
6	455	19.6	2.0	1.57	3,857	2.1	5,046	1,189	.....	.53	....
5	434	19.2	3.2	2.49	5,836	5.0	11,718	5,882	.....	2.51	....
4	346	20.5	2.7	2.16	4,036	3.3	6,166	3,130	.....	1.14	....
3	378	16.8	1.8	1.13	2,307	1.4	2,858	551	.....	.27	....
2	302	16.7	1.5	1.09	1,778	1.1	1,794	16	.....	.01	....
1	260	13.6	1.7	1.11	1,558	1.1	1,544	.....	14	....	0.01

NOTE: Same time of flow as February is used because same flow existed during most of month. The rapid rise in the last week of March accounts for high monthly average.

OXYGEN REQUIREMENTS UNDER ICE COVERAGE
(Based On Oxygen Demand From The Station Specified To Lake Winnipeg)
Critical Winter Season Averages—Dec. 1, 1938 To April 1, 1939
Table XXIII—10

Station	Flow	Time of Flow to Lake Winnipeg	Five Day 20°C B.O.D.	0°C B.O.D. for Time of Flow to Lake Winnipeg	Oxygen Demand at 0°C for Time of Flow to Lake Winnipeg	Dissolved Oxygen Available	Dissolved Oxygen Available	OXYGEN RELATIONSHIPS: Surplus Over Demand Only	OXYGEN RELATIONSHIPS: Deficit Due to Demand Only	OXYGEN RELATIONSHIPS: Surplus Over Demand Only	OXYGEN RELATIONSHIPS: Deficit Due to Demand Only
	C.F.S.	Days	P.P.M.	P.P.M.	Lbs.	P.P.M.	Lbs.	Lbs.	Lbs.	P.P.M.	P.P.M.
6	280	24.7	6.07	5.20	7,862	4.05	5,341	.....	2,521	....	1.15
5	275	23.9	5.2	4.40	6,534	3.78	5,948	.....	586	....	.62
4	252	23.8	5.58	4.80	6,532	1.90	2,884	.....	3,648	....	2.90
3	260	20.0	5.25	4.15	5,827	0.72	1,184	.....	4,643	....	3.43
2	240	18.7	5.08	3.91	5,067	0.45	681	.....	4,386	....	3.46
1	224	14.6	5.02	3.42	4,137	0.37	484	.....	3,653	....	3.05

NOTE: Values shown here are averages of monthly averages for which reason figures from column to column do not check mathematically.

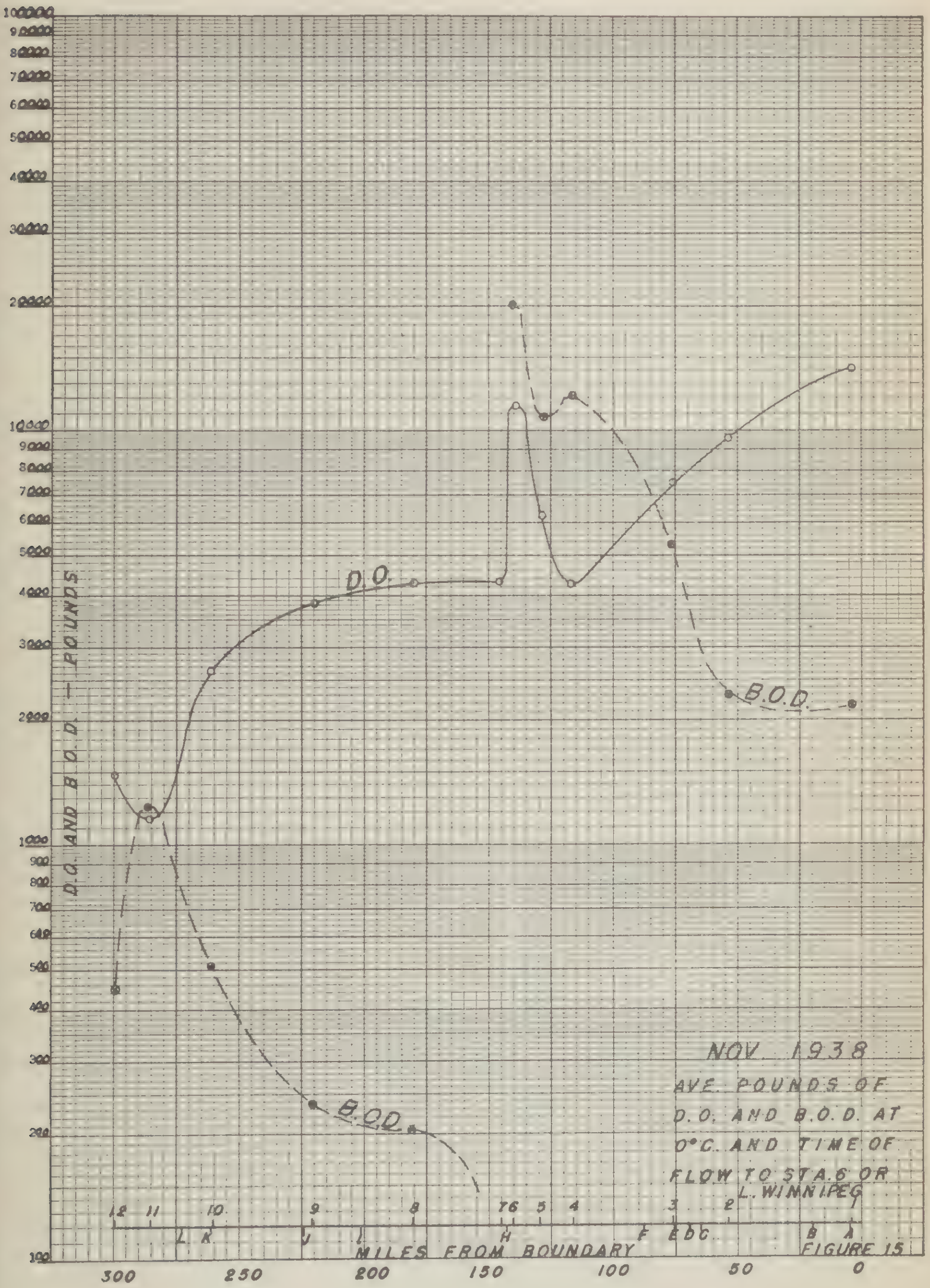
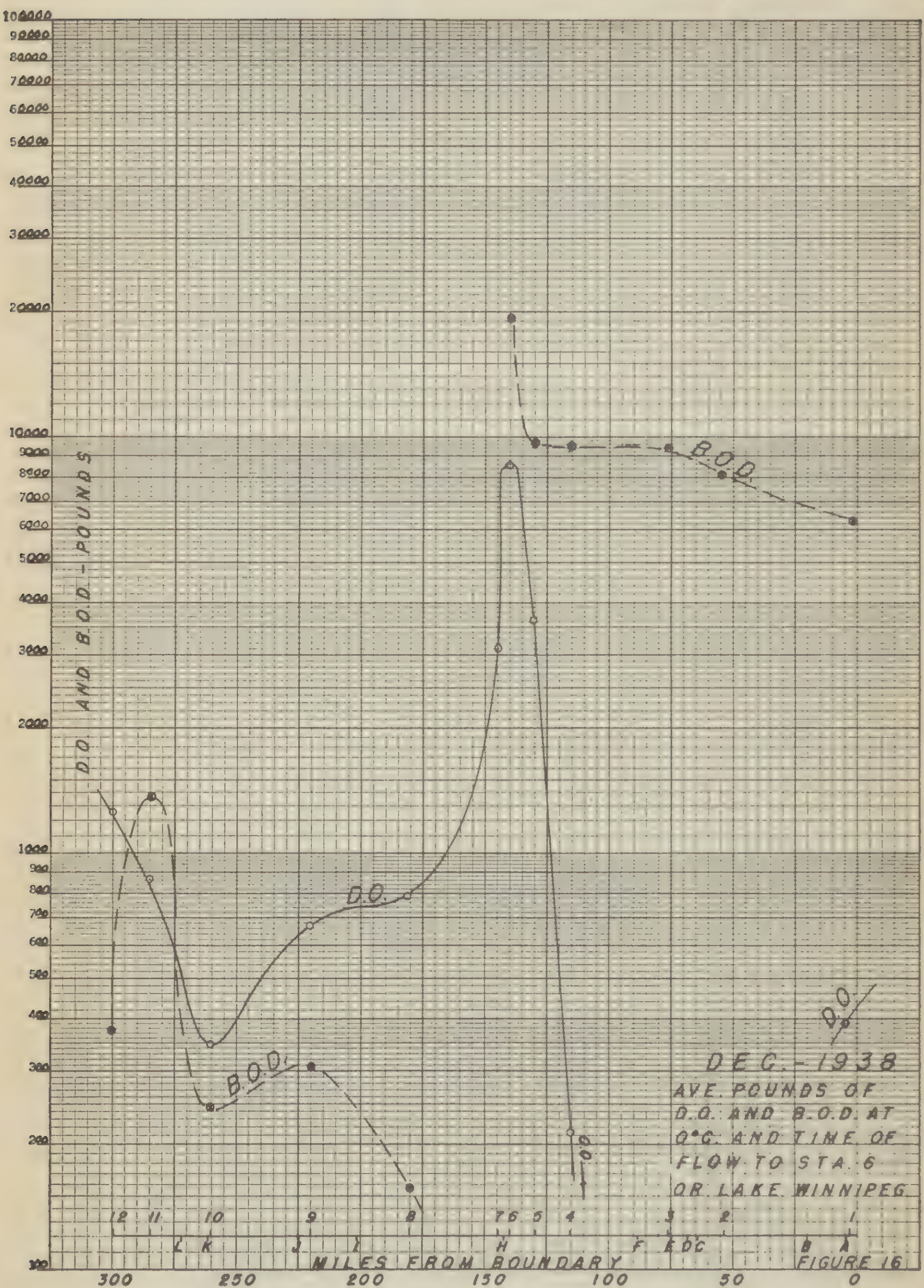
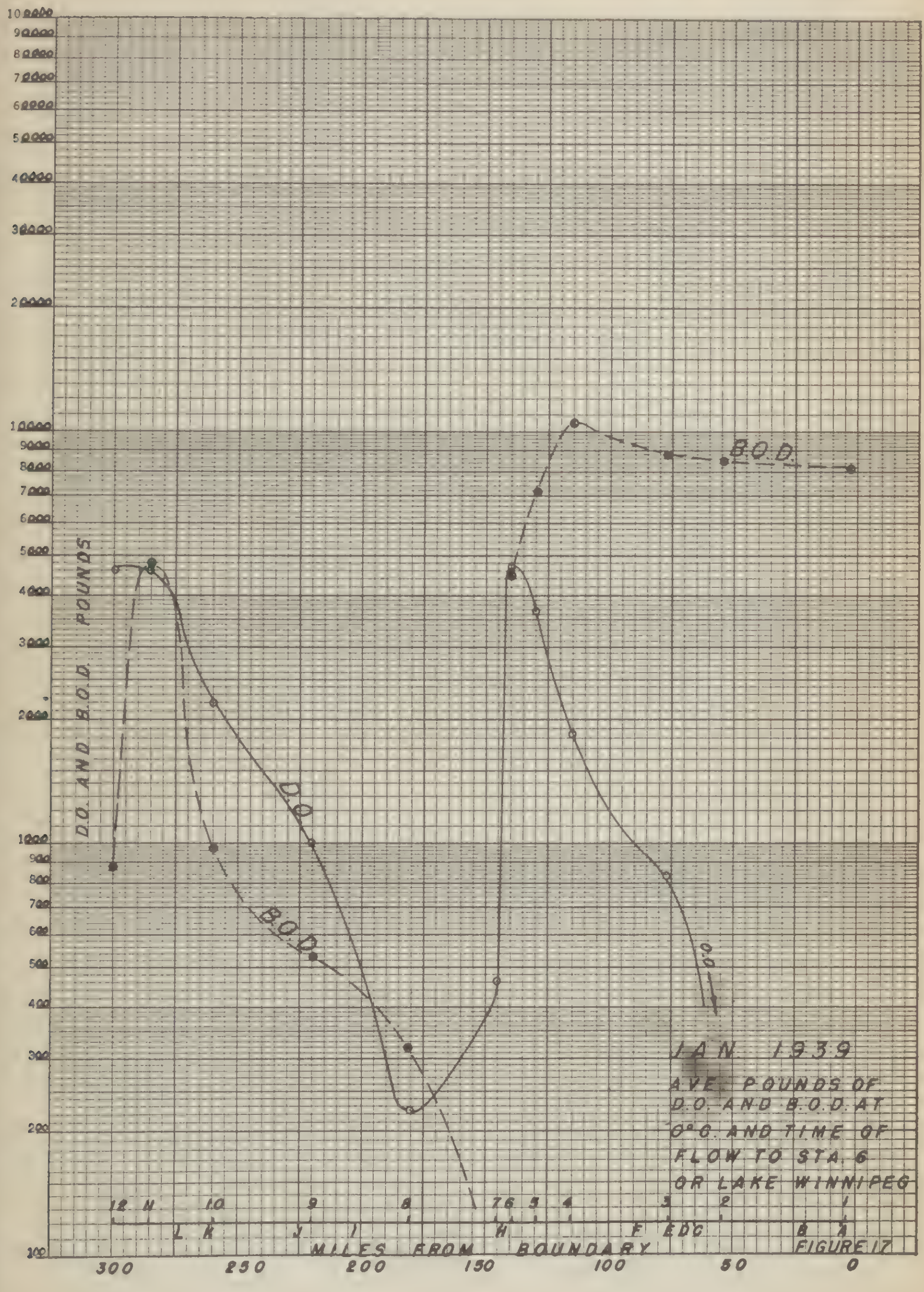
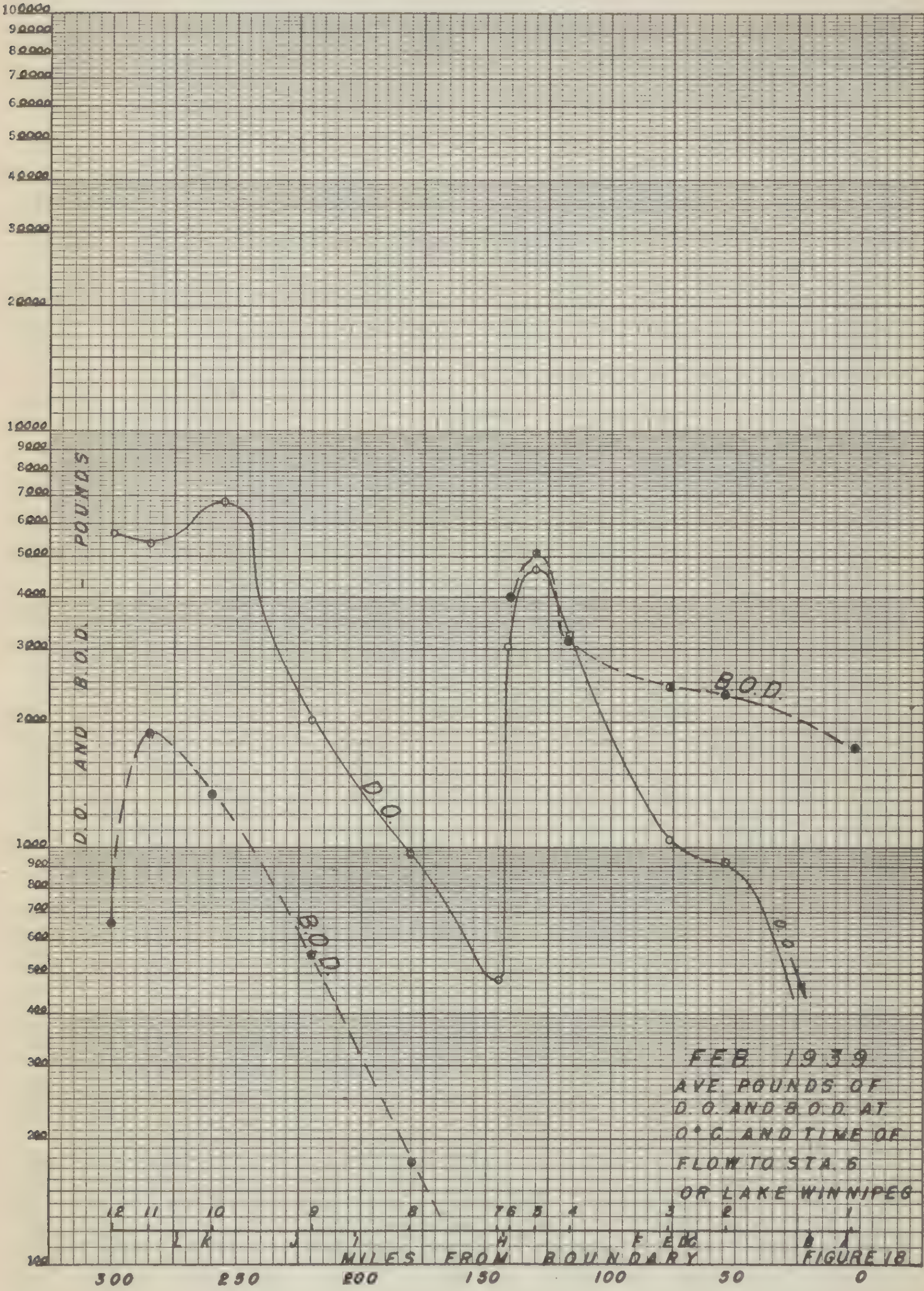

D.O. AND B.O.D. — POUNDS
D.O.
B.O.D.
B.O.D.
NOV. 1938
AVE. POUNDS OF
D.O. AND B.O.D. AT
0°C. AND TIME OF
FLOW TO STA.6 OR
L. WINNIPEG
MILES FROM BOUNDARY
300
250
200
150
100
50
0
100000
10000
1000
100

FIGURE 15

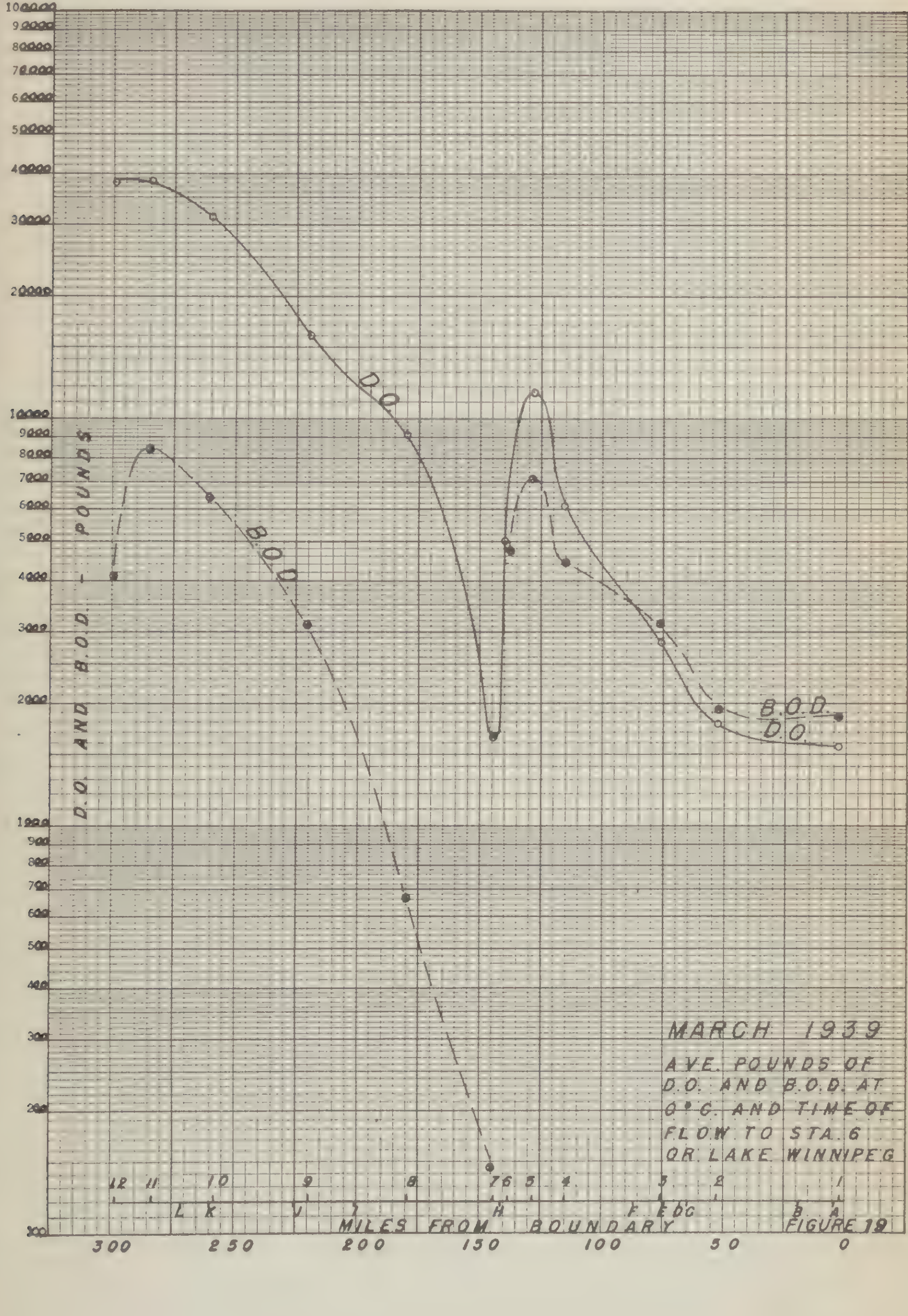


D.O. AND B.O.D. - POUNDS
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
B.O.D.
D.O.
DEC. - 1938
AVE. POUNDS OF D.O. AND B.O.D. AT 0°C. AND TIME OF FLOW TO STA. 6 OR LAKE WINNIPEG.
12 11 10 9 8 7 6 5 4 3 2 1
L K J I H F E D C B A
MILES FROM BOUNDARY
300 250 200 150 100 50 0
FIGURE 16


D.O. AND B.O.D. POUNDS
B.O.D.
D.O.
JAN. 1939
AVE. POUNDS OF D.O. AND B.O.D. AT 0°C. AND TIME OF FLOW TO STA. 6 OR LAKE WINNIPEG
MILES FROM BOUNDARY
300
250
200
150
100
50
0
FIGURE 17



D.O. AND B.O.D. POUNDS
B.O.D.
D.O.
FEB. 1939
AVE. POUNDS OF D.O. AND B.O.D. AT 0° C. AND TIME OF FLOW TO STA. 6 OR LAKE WINNIPEG
MILES FROM BOUNDARY
300 250 200 150 100 50 0
FIGURE 18



D.O. AND B.O.D. – POUNDS
D.O.
B.O.D.
B.O.D.
D.O.
MARCH 1939
AVE. POUNDS OF D.O. AND B.O.D. AT 0° C. AND TIME OF FLOW TO STA. 6 OR LAKE WINNIPEG
MILES FROM BOUNDARY
300
250
200
150
100
50
0

FIGURE 19

OXYGEN REQUIREMENTS UNDER ICE COVERAGE
(Based On Oxygen Demand From The Station Specified To Grand Forks)
December 1939
Table XXIV—1

Station	Flow	Time of Flow to Grand Forks	Five Day 20°C B.O.D.	0°C B.O.D. For Time of Flow to Grand Forks	Oxygen Demand at 0°C for Time of Flow To Grand Forks	Dissolved Oxygen Available	Dissolved Oxygen Available	OXYGEN RELATIONSHIPS: Surplus Over Demand Only	OXYGEN RELATIONSHIPS: Deficit Due to Demand Only	OXYGEN RELATIONSHIPS: Surplus Over Demand Only	OXYGEN RELATIONSHIPS: Deficit Due to Demand Only
	C.F.S.	Days	P.P.M.	P.P.M.	Lbs. Daily	P.P.M.	Lbs. Daily	Lbs. Daily	Lbs. Daily	P.P.M.	P.P.M.
12	17	28.8	2.8	2.5	229	12.6	1,157	928	.....	10.1	....
11	19	25.8	20.7	18.7	1,918	8.8	903	.....	1,015	....	9.9
10	34	20.2	6.1	4.8	881	9.3	1,707	626	.....	4.5	....
9	47	12.9	3.1	2.0	510	15.1	3,847	3,337	.....	13.1	....
8	38	6.8	4.2	1.7	349	15.5	3,181	2,832	.....	13.8	....
7	28	.9	3.9	0.3	45	19.9	3,009	2,964	.....	19.6	....

OXYGEN REQUIREMENTS UNDER ICE COVERAGE
(Based On Oxygen Demand From The Station Specified To Grand Forks)
January 1940
Table XXIV—2

Station	Flow	Time of Flow to Grand Forks	Five Day 20°C B.O.D.	0°C B.O.D. For Time of Flow to Grand Forks	Oxygen Demand at 0°C for Time of Flow To Grand Forks	Dissolved Oxygen Available	Dissolved Oxygen Available	OXYGEN RELATIONSHIPS: Surplus Over Demand Only	OXYGEN RELATIONSHIPS: Deficit Due to Demand Only	OXYGEN RELATIONSHIPS: Surplus Over Demand Only	OXYGEN RELATIONSHIPS: Deficit Due to Demand Only
	C.F.S.	Days	P.P.M.	P.P.M.	Lbs. Daily	P.P.M.	Lbs. Daily	Lbs. Daily	Lbs. Daily	P.P.M.	P.P.M.
12	4.5	64	3.3	5.6	136	9.2	224	88	.....	3.6	....
11	5.6	57.9	26.0	27.0	816	3.2	97	.....	816	....	23.8
10	5	45.6	7.5	8.3	224	0.9	24	.....	200	....	7.4
9	11	25.6	7.7	6.6	392	3.7	220	.....	172	....	2.9
8	14	12.1	6.4	3.9	294	5.6	423	129	.....	1.7	....
7	9	2.1	3.0	0.5	24	18.6	904	880	.....	18.1	....

OXYGEN REQUIREMENTS UNDER ICE COVERAGE
(Based On Oxygen Demand From The Station Specified To Grand Forks)
February 1940
Table XXIV—3

Station	Flow	Time of Flow to Grand Forks	Five Day 20°C B.O.D.	0°C B.O.D. For Time of Flow to Grand Forks	Oxygen Demand at 0°C for Time of Flow To Grand Forks	Dissolved Oxygen Available	Dissolved Oxygen Available	OXYGEN RELATIONSHIPS: Surplus Over Demand Only	OXYGEN RELATIONSHIPS: Deficit Due to Demand Only	OXYGEN RELATIONSHIPS: Surplus Over Demand Only	OXYGEN RELATIONSHIPS: Deficit Due to Demand Only
	C.F.S.	Days	P.P.M.	P.P.M.	Lbs. Daily	P.P.M.	Lbs. Daily	Lbs. Daily	Lbs. Daily	P.P.M.	P.P.M.
12	11	53.3	2.6	4.5	267	5.3	315	48	.....	0.8	....
11	12	49.3	24.7	25.1	1,626	2.6	168	.....	1,456	....	22.5
10	11	41.1	11.0	11.3	671	0.0	0	.....	671	....	11.3
9	14	27.5	12.6	11.1	839	0.0	0	.....	839	....	11.1
8	8	16	22.4	16.0	691	0.0	0	.....	691	....	16.0
7	5	2	....	....	...	12.0	324	.....	.....	...	

OXYGEN REQUIREMENTS UNDER ICE COVERAGE
(Based On Oxygen Demand From The Station Specified To Grand Forks)
March 1940
Table XXIV—4

Station	Flow	Time of Flow to Grand Forks	Five Day 20°C B.O.D.	0°C B.O.D. For Time of Flow to Grand Forks	Oxygen Demand at 0°C for Time of Flow To Grand Forks	Dissolved Oxygen Available	Dissolved Oxygen Available	OXYGEN RELATIONSHIPS: Surplus Over Demand Only	OXYGEN RELATIONSHIPS: Deficit Due to Demand Only	OXYGEN RELATIONSHIPS: Surplus Over Demand Only	OXYGEN RELATIONSHIPS: Deficit Due to Demand Only
	C.F.S.	Days	P.P.M.	P.P.M.	Lbs. Daily	P.P.M.	Lbs. Daily	Lbs. Daily	Lbs. Daily	P.P.M.	P.P.M.
12	40	21.4	....	...	.....	...	.....	.....	.....	....	....
11	41	19.5	....	...	.....	...	.....	.....	.....	....	....
10	59	15.6	13.2	9.2	2,931	1.14	363	.....	2,568	....	8.06
9	77	10.0	12.0	6.4	2,661	0.0	0	.....	2,661	....	6.4
8	80	4.9	21.3	6.9	2,980	0.0	0	.....	2,980	....	6.9
7	73	0.6	....	...	.....	..	.....	.....	.....	....	...

OXYGEN AND FLOW REQUIREMENTS
Fargo (Sta. 11) To Grand Forks (Sta. 6)
November 1938
Table XXV—1

Station 11		Station	Time of Flow From Sta. 11 To Sta. Shown	Oxygen Demand at 0°C. for Time of Flow			Total Lbs. Per Day Sta. 11 to Grand Forks	Flow in C.F.S. Required at Fargo for Indicated Available** P.P.M. of Oxygen			
Flow	5-Day 20°C. B.O.D.			From Sta. 11 To Sta. Shown	From Sta. 11 To Sta. Shown	From Sta. Shown to Grand Forks					
C.F.S.	P.P.M.		Days	P.P.M.	Lbs. Daily	Lbs. Daily		1	2	3	4
23	13.1	11	0	0	0	1,335	1,335	...	...	...	...
..	....	10	5	4.25	528	564	1,092	...	...	...	...
..	....	9	11.3	7.70	957	248	1,205	...	...	...	...
..	....	8	16.8	9.60	1,192	191	1,383*	256	128	85	64
..	....	7	21.4	10.66	1,325	45	1,370	...	...	...	...
..	....	6	22	10.75	1,335	0	1,335	...	...	...	...

*Critical point. This amount must be furnished at Fargo and flow requirements are calculated on the basis of this value.
**Available for the oxidation of untreated or treated sewage and other wastes only. Does not include amount necessary to sustain fish life or other requirements of stream sanitation.

OXYGEN AND FLOW REQUIREMENTS
Fargo (Sta. 11) To Grand Forks (Sta. 6)
December 1938
Table XXV—2

Station 11		Station	Time of Flow From Sta. 11 To Sta. Shown	Oxygen Demand at 0°C. for Time of Flow			Total Lbs. Per Day Sta. 11 to Grand Forks	Flow in C.F.S. Required at Fargo for Indicated Available** P.P.M. of Oxygen			
Flow	5-Day 20°C. B.O.D.			From Sta. 11 To Sta. Shown	From Sta. 11 To Sta. Shown	From Sta. Shown to Grand Forks					
C.F.S.	P.P.M.		Days	P.P.M.	Lbs. Daily	Lbs. Daily		1	2	3	4
25	12.3	11	0	0	0	1,377	1,377	...	...	...	...
..	....	10	5.0	4.0	540	246	786	...	...	...	...
..	....	9	11.8	7.4	1,000	308	1,308	...	...	...	...
..	....	8	17.6	9.1	1,228	151	1,379	...	...	...	...
..	....	7	22.5	10.1	1,362	64	1,426*	264	132	88	66
..	....	6	23.2	10.2	1,377	0	1,377	...	...	...	...

*Critical point. This amount must be furnished at Fargo and flow requirements are calculated on the basis of this value.
**Available for the oxidation of untreated or treated sewage and other wastes only. Does not include amount necessary to sustain fish life or other requirements of stream sanitation.

OXYGEN AND FLOW REQUIREMENTS
Grand Forks (Sta. 6) To Lake Winnipeg
December 1938
Table XXV—3

Station 6		Station	Time of Flow From Sta. 6 To Sta. Shown	Oxygen Demand at 0°C. for Time of Flow			Total Lbs. Per Day Sta. 6 to Lake Winnipeg	Flow in C.F.S. Required at Grand Forks for Indicated Available** P.P.M. of Oxygen			
Flow	5-Day 20°C. B.O.D.			From Sta. 6 To Sta. Shown	From Sta. 6 To Sta. Shown	From Sta. Shown to L. Winnipeg					
C.F.S.	P.P.M.		Days	P.P.M.	Lbs. Daily	Lbs. Daily		1	2	3	4
199	17.3	6	0	0	0	16,656	16,656	.....	.....	.....	...
...	....	5	1.2	1.55	1,666	8,767	10,433	.....	.....	.....	...
...	....	4	2.4	2.94	3,159	8,361	11,520	.....	.....	.....	...
...	....	3	6.2	6.66	7,157	8,251	15,408	.....	.....	.....	...
...	....	2	8.6	8.49	9,123	7,276	16,399	.....	.....	.....	...
...	....	1	13.5	11.28	12,121	5,337	17,458*	3,233	1,617	1,078	808
...	....	L.W.	28.8	15.50	16,656	0	16,656	.....	.....	.....	.

*Critical point. This amount must be furnished at Fargo and flow requirements are calculated on the basis of this value.
**Available for the oxidation of untreated or treated sewage and other wastes only. Does not include amount necessary to sustain fish life or other requirements of stream sanitation.

OXYGEN AND FLOW REQUIREMENTS
Fargo (Sta. 11) To Grand Forks (Sta. 6)
January 1939
Table XXV—4

Station 11		Station	Time of Flow From Sta. 11 To Sta. Shown	Oxygen Demand at 0°C. for Time of Flow			Total Lbs. Per Day Sta. 11 to Grand Forks	Flow in C.F.S. Required at Fargo for Indicated Available** P.P.M. of Oxygen			
Flow	5-Day 20°C. B.O.D.			From Sta. 11 To Sta. Shown	From Sta. 11 To Sta. Shown	From Sta. Shown to Grand Forks					
C.F.S.	P.P.M.		Days	P.P.M.	Lbs. Daily	Lbs. Daily		1	2	3	4
98	11.4	11	0	0	0	4,657	4,657	...	...	...	...
..	....	10	2.8	2.3	1,220	975	2,195	...	...	...	...
..	....	9	7.5	5.0	2,650	529	3,179	...	...	...	...
..	....	8	12.1	7.1	3,760	321	4,081	...	...	...	...
..	....	7	16.3	8.4	4,450	42	4,492	...	...	.	...
..	....	6	16.9	8.8	4,657	0	4,657*	862	431	287	215

*Critical point. This amount must be furnished at Fargo and flow requirements are calculated on the basis of this value.
**Available for the oxidation of untreated or treated sewage and other wastes only. Does not include amount necessary to sustain fish life or other requirements of stream sanitation.

OXYGEN AND FLOW REQUIREMENTS
Grand Forks (Sta. 6) To Lake Winnipeg
January 1939
Table XXV—5

Station 6		Station	Time of Flow From Sta. 6 To Sta. Shown	Oxygen Demand at 0°C. for Time of Flow			Total Lbs. Per Day Sta. 6 to Lake Winnipeg	Flow in C.F.S. Required at Grand Forks for Indicated Available** P.P.M. of Oxygen			
Flow	5-Day 20°C. B.O.D.			From Sta. 6 To Sta. Shown	From Sta. 6 To Sta. Shown	From Sta. Shown to L. Winnipeg					
C.F.S.	P.P.M.		Days	P.P.M.	Lbs. Daily	Lbs. Daily		1	2	3	4
235	2.7	6	0	0	0	3,020	3,020	.....	...	...	...
...	....	5	1.1	.22	279	5,926	6,205	.....	...	...	...
...	....	4	2.3	.45	571	9,231	9,802*	1,815	908	605	454
...	....	3	5.8	.98	1,244	7,829	9,073	.....	...	...	...
...	....	2	8.0	1.26	1,599	7,558	9,157	.....	...	...	...
...	....	1	12.5	1.68	2,132	6,800	8,932	.....	...	...	...
...	....	L.W.	26.7	2.36	3,020	0	3,020	.....	...	...	...

*Critical point. This amount must be furnished at Fargo and flow requirements are calculated on the basis of this value.
**Available for the oxidation of untreated or treated sewage and other wastes only. Does not include amount necessary to sustain fish life or other requirements of stream sanitation.

OXYGEN AND FLOW REQUIREMENTS
Fargo (Sta. 11) To Grand Forks (Sta. 6)
February 1939
Table XXV—6

Station 11		Station	Time of Flow From Sta. 11 To Sta. Shown	Oxygen Demand at 0°C. for Time of Flow			Total Lbs. Per Day Sta. 11 to Grand Forks	Flow in C.F.S. Required at Fargo for Indicated Available** P.P.M. of Oxygen			
Flow	5-Day 20°C. B.O.D.			From Sta. 11 To Sta. Shown	From Sta. 11 To Sta. Shown	From Sta. Shown to Grand Forks					
C.F.S.	P.P.M.		Days	P.P.M.	Lbs. Daily	Lbs. Daily		1	2	3	4
102	4.8	11	0	0	0	1,873	1,873	...	...	...	...
...	....	10	2.7	0.90	496	1,322	1,818	...	...	...	...
...	....	9	7.3	2.00	1,100	554	1,654	...	...	...	...
...	....	8	11.6	2.84	1,565	172	1,737	...	...	...	...
...	....	7	15.5	3.36	1,850	53	1,903*	363	182	121	91
...	....	6	16.0	3.40	1,873	0	1,873	...	...	...	...

*Critical point. This amount must be furnished at Grand Forks and flow requirements are calculated on the basis of this value.
**Available for the oxidation of untreated or treated sewage and other wastes only. Does not include amount necessary to sustain fish life or other requirements of stream sanitation.

OXYGEN AND FLOW REQUIREMENTS
Grand Forks (Sta. 6) To Lake Winnipeg
February 1939
Table XXV—7

Station 6		Station	Time of Flow From Sta. 6 To Sta. Shown	Oxygen Demand at 0°C. for Time of Flow			Total Lbs. Per Day Sta. 6 to Lake Winnipeg	Flow in C.F.S. Required at Grand Forks for Indicated Available** P.P.M. of Oxygen			
Flow	5-Day 20°C. B.O.D.			From Sta. 6 To Sta. Shown	From Sta. 6 To Sta. Shown	From Sta. Shown to L. Winnipeg					
C.F.S.	P.P.M.		Days	P.P.M.	Lbs. Daily	Lbs. Daily		1	2	3	4
229	2.3	6	0	0	0	2,498	2,498	...	...	...	...
...	....	5	1.1	.19	235	3,809	4,044*	749	375	250	187
...	....	4	2.4	.39	482	2,047	2,529	...	...	...	...
...	....	3	6.2	.89	1,100	2,008	3,108	...	...	...	...
...	....	2	8.5	1.12	1,384	2,032	3,416	...	...	...	...
...	....	1	13.3	1.49	1,843	1,446	3,289	...	...	...	...
...	....	L.W.	27.0	2.02	2,498	0	2,498	...	...	...	...

*Critical point. This amount must be furnished at Grand Forks and flow requirements are calculated on the basis of this value.
**Available for the oxidation of untreated or treated sewage and other wastes only. Does not include amount necessary to sustain fish life or other requirements of stream sanitation.

OXYGEN AND FLOW REQUIREMENTS
Fargo (Sta. 11) To Grand Forks (Sta. 6)
March 1939
Table XXV—8

Station 11		Station	Time of Flow From Sta. 11 To Sta. Shown	Oxygen Demand at 0°C. for Time of Flow			Total Lbs. Per Day Sta. 11 to Grand Forks	Flow in C.F.S. Required at Fargo for Indicated Available** P.P.M. of Oxygen			
Flow	5-Day 20°C. B.O.D.			From Sta. 11 To Sta. Shown	From Sta. 11 To Sta. Shown	From Sta. Shown to Grand Forks					
C.F.S.	P.P.M.		Days	P.P.M.	Lbs. Daily	Lbs. Daily		1	2	3	4
743	5.8	11	0	0	0	8,426	8,426*	1,560	780	530	390
...	....	10	1	.44	1,765	6,464	8,229	.....	...	...	...
...	....	9	2.4	1.00	4,020	3,123	7,143	.....	...	...	...
...	....	8	4.0	1.56	6,260	679	6,939	.....	...	...	...
...	....	7	5.5	2.03	8,150	148	8,298	.....	...	...	...
...	....	6	5.8	2.10	8,426	0	8,426	.....	...	...	...

*Critical point. This amount must be furnished at Grand Forks and flow requirements are calculated on the basis of this value.
**Available for the oxidation of untreated or treated sewage and other wastes only. Does not include amount necessary to sustain fish life or other requirements of stream sanitation.

OXYGEN AND FLOW REQUIREMENTS
Grand Forks (Sta. 6) To Lake Winnipeg
March 1939
Table XXV—9

Station 6		Station	Time of Flow From Sta. 6 To Sta. Shown	Oxygen Demand at 0°C. for Time of Flow			Total Lbs. Per Day Sta. 6 to Lake Winnipeg	Flow in C.F.S. Required at Grand Forks for Indicated Available** P.P.M. of Oxygen			
Flow	5-Day 20°C. B.O.D.			From Sta. 6 To Sta. Shown	From Sta. 6 To Sta. Shown	From Sta. Shown to L. Winnipeg					
C.F.S.	P.P.M.		Days	P.P.M.	Lbs. Daily	Lbs. Daily		1	2	3	4
455	2.0	6	0	0	0	3,857	3,857	.....	...	...	...
...	....	5	0.5	.08	197	5,836	6,033*	1,117	559	372	279
...	....	4	1.1	.16	393	4,036	4,429	.....	...	...	...
...	....	3	2.8	.40	983	2,307	3,290	.....	...	...	...
...	....	2	3.8	.51	1,253	1,778	3,031	.....	...	...	...
...	....	1	6.0	.75	1,843	1,558	3,401	.....	...	...	...
...	....	L.W.	19.6	1.57	3,857	0	3,857	.....	...	...	...

*Critical point. This amount must be furnished at Grand Forks and flow requirements are calculated on the basis of this value.
**Available for the oxidation of untreated or treated sewage and other wastes only. Does not include amount necessary to sustain fish life or other requirements of stream sanitation.

OXYGEN AND FLOW REQUIREMENTS
Grand Forks (Sta. 6) To Lake Winnipeg
Critical Winter Season Averages
Dec. 1, 1938 to April 1, 1939
Table XXV—10

Station 6		Station	Time of Flow From Sta. 6 To Sta. Shown	Oxygen Demand at 0°C. for Time of Flow			Total Lbs. Per Day Sta. 6 to Lake Winnipeg	Flow in C.F.S. Required at Grand Forks for Indicated Available** P.P.M. of Oxygen			
Flow	5-Day 20°C. B.O.D.			From Sta. 6 To Sta. Shown	From Sta. 6 To Sta. Shown	From Sta. Shown to L. Winnipeg					
C.F.S.	P.P.M.		Days	P.P.M.	Lbs. Daily	Lbs. Daily		1	2	3	4
280	6.07	6	0	0	0	7,862	7,862	.....	...	...	...
...	....	5	1.0	.46	696	6,534	7,230	.....	...	...	...
...	....	4	2.1	.92	1,391	6,532	7,923	.....	...	...	...
...	....	3	5.4	2.09	3,160	5,827	8,987	.....	...	...	...
...	....	2	7.4	2.67	4,037	5,067	9,104	.....	...	...	...
...	....	1	11.6	3.62	5,473	4,137	9,610*	1,780	890	593	445
...	....	L.W.	24.7	5.20	7,862	0	7,862	.....	...	...	...

*Critical point. This amount must be furnished at Grand Forks and flow requirements are calculated on the basis of this value.
**Available for the oxidation of untreated or treated sewage and other wastes only. Does not include amount necessary to sustain fish life or other requirements of stream sanitation.

OXYGEN AND FLOW REQUIREMENTS
Fargo (Sta. 11) To Grand Forks (Sta. 6)
December 1939
Table XXVI—1

Station 11		Station	Time of Flow From Sta. 11 To Sta. Shown	Oxygen Demand at 0°C. for Time of Flow			Total Lbs. Per Day Sta. 11 to Grand Forks	Flow in C.F.S. Required at Fargo for Indicated Available** P.P.M. of Oxygen			
Flow	5-Day 20°C. B.O.D.			From Sta. 11 To Sta. Shown	From Sta. 11 To Sta. Shown	From Sta. Shown to Grand Forks					
C.F.S.	P.P.M.		Days	P.P.M.	Lbs. Daily	Lbs. Daily		1	2	3	4
19	20.7	11	0	0	0	1,918	1,918	...	...	...	...
..	....	10	5.6	7.35	755	881	1,636	...	...	...	...
..	....	9	12.9	13.17	1,350	510	1,860	...	...	...	...
..	....	8	19.0	16.05	1,647	349	1,996*	370	185	123	93
..	....	7	24.9	17.70	1,815	45	1,860	...	...	...	...
..	....	6	25.8	18.70	1,920	0	1,920	...	...	...	...

*Critical point. This amount must be furnished at Fargo and flow requirements are calculated on the basis of this value.
**Available for the oxidation of untreated or treated sewage and other wastes only. Does not include amount necessary to sustain fish life or other requirements of stream sanitation.

OXYGEN AND FLOW REQUIREMENTS
Fargo (Sta. 11) To Grand Forks (Sta. 6)
January 1940
Table XXVI—2

Station 11		Station	Time of Flow From Sta. 11 To Sta. Shown	Oxygen Demand at 0°C. for Time of Flow			Total Lbs. Per Day Sta. 11 to Grand Forks	Flow in C.F.S. Required at Fargo for Indicated Available** P.P.M. of Oxygen			
Flow	5-Day 20°C. B.O.D.			From Sta. 11 To Sta. Shown	From Sta. 11 To Sta. Shown	From Sta. Shown to Grand Forks					
C.F.S.	P.P.M.		Days	P.P.M.	Lbs. Daily	Lbs. Daily		1	2	3	4
5.6	26.0	11	0	0	0	816	816	...	...	...	...
...	....	10	12.3	16.1	487	224	711	...	...	...	...
...	....	9	32.3	23.9	724	392	1,116*	206	103	67	52
...	....	8	45.8	26.0	786	294	1,080	...	...	...	...
...	....	7	55.8	26.8	810	24	834	...	...	...	...
...	....	6	57.9	27.0	816	0	816	...	...	...	...

*Critical point. This amount must be furnished at Fargo and flow requirements are calculated on the basis of this value.
**Available for the oxidation of untreated or treated sewage and other wastes only. Does not include amount necessary to sustain fish life or other requirements of stream sanitation.

OXYGEN AND FLOW REQUIREMENTS
Fargo (Sta. 11) To Grand Forks (Sta. 6)
February 1940
Table XXVI—3

Station 11		Station	Time of Flow From Sta. 11 To Sta. Shown	Oxygen Demand at 0°C. for Time of Flow			Total Lbs. Per Day Sta. 11 to Grand Forks	Flow in C.F.S. Required at Fargo for Indicated Available** P.P.M. of Oxygen			
Flow	5-Day 20°C. B.O.D.			From Sta. 11 To Sta. Shown	From Sta. 11 To Sta. Shown	From Sta. Shown to Grand Forks					
C.F.S.	P.P.M.		Days	P.P.M.	Lbs. Daily	Lbs. Daily		1	2	3	4
12	24.7	11	0	0	0	1,626	1,626	...	...	...	...
..	....	10	8.2	11.7	760	671	1,431	...	...	...	...
..	....	9	21.8	20.2	1,310	839	2,149	...	...	...	...
..	....	8	33.3	23.0	1,490	691	2,181*	404	202	135	101
..	....	6	49.3	25.2	1,626	0	1,626	...	...	...	...

*Critical point. This amount must be furnished at Fargo and flow requirements are calculated on the basis of this value.

**Available for the oxidation of untreated or treated sewage and other wastes only. Does not include amount necessary to sustain fish life or other requirements of stream sanitation.

APPENDIX I

Hydrometric Data

VELOCITIES IN RED RIVER AND TIMES OF FLOW

Stream gaging and flow computations are functions of the U. S. Geological Survey, which agency works in cooperation with the State Engineer. Unfortunately, sufficient stream measurements, with particular respect to determining more definitely the time required for passage of a given mass of water from point to point, were not made during the period of the field investigations because it was assumed that sufficiently accurate estimates could be made from available records. It would no doubt have been better to have requested the desired flow data at the inception of the investigation, thus allowing time for making accurate measurements for the duration of the study, especially during ice coverage periods.

As a result of a conference with Mr. Paul R. Speer, District Engineer, U. S. Geological Survey, a man was detailed to study the flow characteristics of the Red River and tributaries with the end in view of estimating (1) the mean flows at the sampling stations and (2) the time interval between occurrence of specific discharges at the various points in the stream. Computations were checked by the office of the North Dakota State Engineer, E. J. Thomas.

Gaging stations on the Red River are maintained at Emerson, Manitoba, (computed by Department of Interior, Dominion Water Power and Hydrometric Bureau); Grand Forks, North Dakota; and Fargo, North Dakota.

Inflow from tributaries was estimated from gaging-station records, by transposing the figures downstream on the basis of the estimated time required for the movement through the stream distance.

"It should be understood that the discharge figures, except at gaging stations, do not represent actual stream-flow records. They are estimates based on such actual gaging-station records as are available. There is a good possibility that erroneous assumptions may have been made in arriving at the time intervals between occurrence of specific discharges at the various points in estimating unmeasured inflow, losses, etc." *

RED RIVER

Time Interval Between Occurrence of Specific Discharges in Reach from Grand Forks, North Dakota to Emerson, Manitoba
(Approximate River Mileage—146 miles)

"The following table gives an approximation of the time interval between occurrence of specific discharges between Grand Forks, North Dakota and Emerson, Manitoba. These values were arrived at through a study of discharge hydrographs for the gaging stations at Grand Forks and Emerson. As the cross-sectional area of the channel varies considerably from point to point along the reach,

*Paul R. Speer, District Engineer, U.S.G.S.

these values cannot be applied to any selected place along the river. They represent only the approximate mean through a considerable length of the river. The time interval for a given discharge will also vary considerably, as the conditions vary from one of rapidly increasing rate of discharge through a constant rate to a rapidly decreasing rate. Another factor affecting the interval is the varying amount of aquatic growth in the channel." *

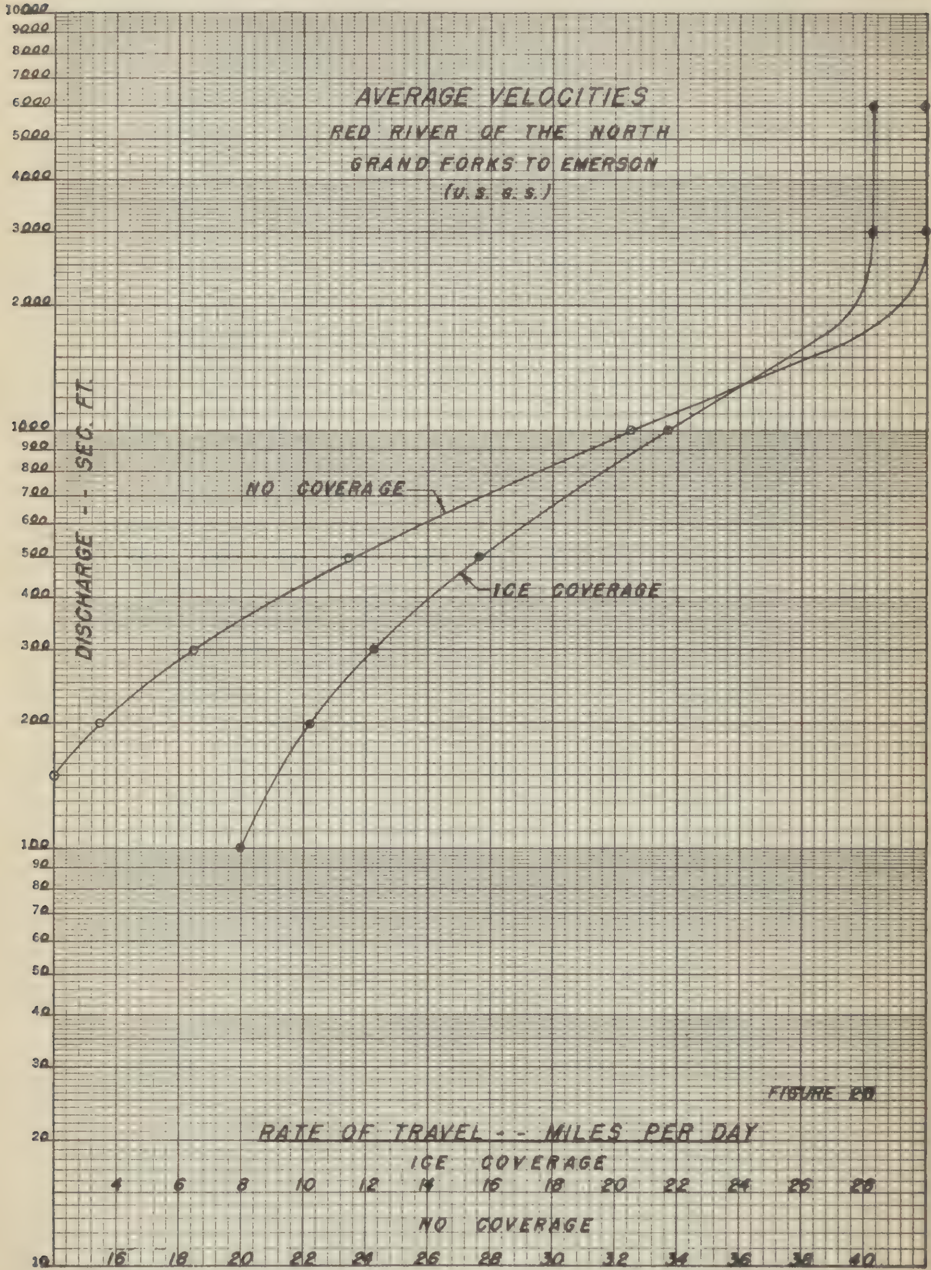
Table I

TIME INTERVAL BETWEEN OCCURRENCE OF SPECIFIC DISCHARGES
(by U.S.G.S.)

Discharge in second-feet	Approximate time of travel in days Grand Forks to Emerson		Approximate rate of travel Miles per day	
	Rapidly rising stage	Constant to falling stage	Rapidly rising stage	Constant to falling stage
6,000	3	4	49	36
3,000	3	4	49	36
1,000	4	5	36	29
500	5	8	29	18
300	6	11	24	13
200	7	15	21	10
100	10	16	15	9

NOTE: The above values are for open-water conditions. The general trend under conditions of ice cover is toward lower mean velocities in the channel, undoubtedly, resulting in longer time intervals between observation points. The amount of decrease in mean velocity varies greatly under varying conditions of ice cover. The average mean velocity under ice cover is probably about 2/3 of that for the same open-water discharge. This figure cannot be applied for short individual periods, however, with any assurance of reasonable accuracy.

*P. R. Speer, Dist. Engr. U.S.G.S.



AVERAGE VELOCITIES
RED RIVER OF THE NORTH
GRAND FORKS TO EMERSON
(U.S. G.S.)
DISCHARGE - - SEC. FT.
NO COVERAGE
ICE COVERAGE
RATE OF TRAVEL - - MILES PER DAY
ICE COVERAGE
NO COVERAGE
FIGURE 20

RED RIVER

Rate of Travel of Specific Discharges in Reach from
Fargo, North Dakota to Grand Forks, North Dakota
(Approximate River Mileage—156 miles)
by U.S.G.S.

The following table gives an approximation of the rate of travel of specific discharges between Fargo and Grand Forks, North Dakota. These values were arrived at through a study of discharge hydrographs for the gaging stations at Fargo and Grand Forks, and for the discontinued station at Halstad, Minnesota, and also from discharge measurements at these stations. As the cross-sectional area varies considerably from point to point along the river, these values do not apply to selected points, but represent an approximation of the average rate through a long reach of the river. The rate of travel of a given discharge will also vary considerably as the channel becomes more or less choked with aquatic growth. Still another factor entering into the computations is that of rate of change of rate of discharge, the rate of travel being greater during conditions of rapidly rising stage.

Table II

RATE OF TRAVEL OF SPECIFIC DISCHARGE

Discharge Second-feet	Approximate Rate of Travel Miles Per Day	
	Rapidly Rising Stage	Constant to Falling Stage
50	12	8
150	20	12
250	26	15
500	32	20
1,000	39	32
4,000	40	33

NOTE: See note under table I concerning rate of travel under ice cover.

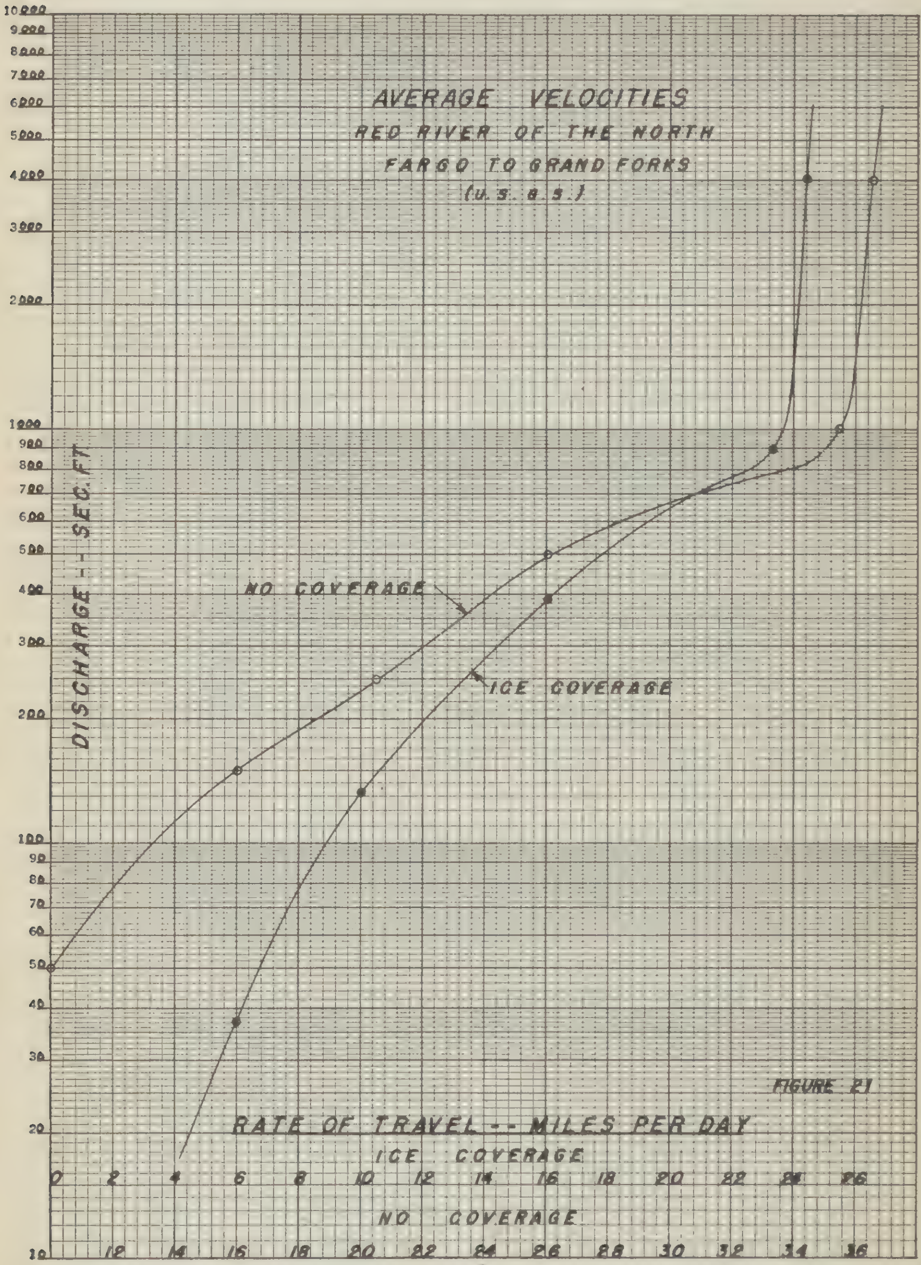

AVERAGE VELOCITIES
RED RIVER OF THE NORTH
FARGO TO GRAND FORKS
(U. S. G. S.)
DISCHARGE -- SEC. FT.
NO COVERAGE
ICE COVERAGE
FIGURE 21
RATE OF TRAVEL -- MILES PER DAY
ICE COVERAGE
0 2 4 6 8 10 12 14 16 18 20 22 24 26
NO COVERAGE
12 14 16 18 20 22 24 26 28 30 32 34 36
10 20 30 40 50 60 70 80 90 100 200 300 400 500 600 700 800 900 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

Table III
STREAM GAGING STATIONS

RED RIVER		TRIBUTARIES			
Location	Type	Location	*Distance from Mouth	Stream	Type
Emerson, Manitoba	Chain Gage	Neche	25	Pembina	Recording
Grand Forks, N. Dak. below Sta. 6	Recording Gage	Cavalier	40	Tongue (Pembina)	Wire weight
Fargo, N. Dak. Between Sta. 11 & 12	Staff Gage	Grafton	24	Park	Chain
		Crookston	45	Red Lake	Recording
		Twin Valley	55	Wild Rice (Minn.)	Recording
		Hillsboro	14	Goose	Chain
		Dilworth	28	Buffalo	Recording
		West Fargo	16	Sheyenne	Recording

*Distances approximately estimated.

The above gaging stations in the United States are maintained by The U. S. Geological Survey. Estimates obtained from that agency are based on records from these stations. Tributaries not listed above are of little or no significance with respect to the pollution problem of the Red River.

Table IV
*MEAN MONTHLY DISCHARGES AT SAMPLING STATIONS C.F.S.

Station	1	2	3	4	5	6	7	8	9	10	11	12	A	D	H	I	J	K	L
1938																			
Nov.	207	199	189	192	190	190	59	62	62	45	23	23	...	...	131	...	17	11	15
Dec.	182	197	200	197	198	199	59	56	57	38	25	25	...	...	141	...	21	8	12
1939																			
Jan.	198	216	219	231	235	237	78	85	98	95	98	97	...	...	159	...	18	6	11
Feb.	255	246	243	234	232	229	99	106	114	102	102	102	...	Start 3-29	130	Start 3-23	18	4	10
Mar.	260	302	378	346	434	455	274	626	723	855	743	743	Start 4-4	3.7	181	85	48	163	96
Apr.	3,690	3,710	3,452	3,170	3,130	3,126	2,450	2,020	1,830	1,420	711	710	34.4	29.4	675	45	262	318	265
May	1,180	1,040	992	951	917	912	458	451	429	320	218	219	18.1	3.3	456	1.2	100	37	64
June	646	681	682	696	692	687	366	344	318	234	135	135	12.4	2.7	320	8.9	72	19	55
July	564	492	461	411	397	388	203	202	190	131	90	92	1.7	.3	185	.2	53	10	28
Aug.	188	157	144	123	121	118	38	41	42	25	17	18	Stop 7-14	Stop 7-16	80	Stop 7-15	16	2	11
Sept.	230	212	216	211	218	225	16	17	21	9	5.2	5.2	...	...	210	...	14	2	9
Oct.	338	337	344	333	334	334	24	26	33	33	15	13	...	...	299	...	16	5	13
Nov.	391	340	334	329	330	332	41	46	49	38	22	21	...	...	292	...	17	8	17
Dec.	384	297	292	301	297	314	28	38	47	34	19	17	...	...	260	...	20	9	18
1940																			
Jan.	139	161	163	173	171	175	9	14	11	5	5.6	4.5	...	...	161	...	9	2	7
Feb.	149	175	178	184	184	186	3	8	14	11	12	11	...	...	282	...	7	1	8
Mar.	225	218	225	225	230	...	73	80	77	59	41	40	...	...	160	...	11	3	7

*Not actual gaging station records. (Except Station 6) Estimates only of flows based on available records. By U.S.G.S.

Table V

AVERAGE STREAM GRADIENTS FOR VARIOUS REACHES OF THE RIVER

	Elevation Ordinary Stage	Drop—feet.	Miles	Drop—ft/mile	Bank Elevation
Lake Traverse	973				990
		17			
Wahpeton	956				963
		86	97	.887	
Fargo	870				900
		86	154	.558	
Grand Forks	784				828
		36	143	.252	
International Boundary	748				780
		15	110	.136	
Winnipeg	733				758

Elevation from Simons and King's Report

Table VI

AVERAGE ANNUAL RUN-OFF OF THE RED RIVER DRAINAGE BASIN

River	Years of Record	Drainage Area	Average Annual Run-Off	Average Flow	Acre Ft. Per Sq. Mi.
		Sq. Mi.	Acre Ft.	Sec. Ft.	
Red River Grand Forks	53	25,500	1,700,000	2,350	67.9
Red River Fargo	32	6,420	375,000	518	59.2
Red Lake River	..	5,760	768,000	1,060	135.8
Pembina River	26	3,530	158,000	218	45.8
Ottertail River	19	1,840	268,000	370	149.3
Bois-de-Sioux River	15	1,860	20,000	27	10.9
Wild Rice River Minnesota	12	1,440	145,000	200	103.3
Sheyenne River	10	7,380	164,000	227	22.8
Two Rivers	9	1,020	103,000	143	103.3
Estimates assisted by records for two or three years:					
Park River	..	1,130	48,000	66	43.4
Red River International Boundary	..	35,895	2,320,000	3,200	66.2
Forest River	..	1,000	54,000	74	53.3
Buffalo River	..	1,400	96,000	133	70.5
Estimates based on records of adjoining streams:					
Tamarac	..	580	46,000	64	79.4
Snake River	..	1,040	83,000	115	80.0
Turtle River	..	700	30,000	41	43.0
Sand Hill	..	530	28,000	39	52.8

Unless otherwise stated the above figures are at the mouth of the River.

All drainage areas shown in table VI were figured by Dean E. F. Chandler, and were carefully measured in square miles from the best available maps. If the location of the station was not at the mouth of the river the run-off was figured in acre feet per square mile of drainage area for that portion and a modification was made by Dean Chandler based upon differences in topography toward the mouth.

The records of run-off at regular stations are entirely from the published records of the U. S. Geological Survey.

The complete fifty-three year record at Grand Forks, North Dakota was used as a control. By proportionment, depending on the percentage of flow of the control station, E. F. Chandler calculated the run-off data for the shorter record periods so as to give an assumed fifty-three year average for all tributaries.

For rivers with no records at all, the run-off figures were merely based on estimates from adjoining streams and topography.

Table VII

ANNUAL DISCHARGES OF THE RED RIVER
Grand Forks, North Dakota

Drainage Area 25,500 Square Miles

Year	Mean Discharge In Sec. Ft.	Run Off Acre Ft.	Days Record
1882	7,181	3,917,300	275
1883	4,302	3,029,100	365
1884	2,936	2,131,100	366
1885	3,158	2,286,600	365
1886	1,858	1,345,200	365
1887	1,007	729,300	365
1888	2,752	1,998,000	366
1889	761	551,200	365
1890	782	565,900	365
1891	1,205	872,500	365
1892	3,782	2,745,200	366
1893	3,499	2,533,400	365
1894	2,086	1,510,000	365
1895	786	569,100	365
1896	3,452	2,505,800	366
1897	5,616	4,065,800	365
1898	1,670	1,209,200	365
1899	2,141	1,549,800	365
1900	1,871	1,354,600	365
1901	3,287	2,379,600	365
1902	1,957	353,369	91
1903	2,997	2,169,535	365
1904	6,152	2,781,920	228
1905	4,790	2,232,900	235
1906	4,619	3,344,300	365
1907	3,557	2,575,100	365
1908	3,081	2,230,600	365
1909	2,666	1,930,400	365
1910	2,362	1,710,000	365
1911	737	533,400	365
1912	870	472,740	274
1912–1913	1,350	977,535	365
1913–1914	1,694	1,226,253	365
1914–1915	2,897	2,096,900	365
1915–1916	5,579	4,051,000	365
1916–1917	2,706	1,959,200	365
1917–1918	966	699,300	365
1918–1919	2,101	1,521,000	365
1919–1920	3,079	2,235,500	366
1920–1921	1,602	1,160,000	365
1921–1922	2,151	1,557,100	365
1922–1923	1,333	965,300	365
1923–1924	731	530,900	366
1924–1925	1,248	902,670	365
1925–1926	1,216	880,500	365
1926–1927	2,603	1,884,800	365
1927–1928	1,796	1,304,000	366
1928–1929	1,728	1,250,800	365
1929–1930	1,226	887,280	365
1930–1931	351	254,000	365
1931–1932	623	451,920	366
1932–1933	401	290,140	365
1933–1934	244	176,430	365
1934–1935	439	317,850	365
1937–1938	894	647,410	365

Table VIII

MONTHLY SUMMARY OF DISCHARGE RECORDS

Grand Forks, North Dakota

Month	Length of Record Days	Total Recorded Runoff Acre Ft.	Average Mean Discharges Sec. Ft.	Maximum Mean Discharge Sec. Ft.	Maximum Mean Discharge Year	Minimum Mean Discharge Sec. Ft.	Minimum Mean Discharge Year
October	1,643	4,123,954	1,265	5,690	1900	31.7	1933
November	1,585	3,675,565	1,169	4,590	1900	73.0	1934
December	1,550	2,613,016	850	2,430	1909	40.7	1934
January	1,550	1,983,841	645	1,830	1901	27.7	1935
February	1,410	1,606,883	575	1,630	1883	31.8	1935
March	1,550	4,956,888	1,612	8,420	1910	234.	1888
April	1,570	24,000,956	7,707	30,500	1897	1,090	1931
May	1,643	14,635,405	4,491	15,240	1893	373	1934
June	1,590	10,457,698	3,316	12,000	1896	151	1934
July	1,643	8,741,897	2,683	11,300	1916	116	1933
August	1,643	5,044,775	1,548	6,640	1897	30.6	1934
September	1,620	3,922,464	1,221	4,507	1905	20.7	1934

Table IX

ANNUAL DISCHARGES OF THE RED RIVER

Fargo, North Dakota

Drainage Area 6,420 Square Miles

Year	Mean Discharge In Sec. Ft.	Run Off Acre Ft.	Days Record
1902	540	300,971	231
1903	530.5	257,786	245
1904	1,061.4	513,660	244
1905	944.6	455,300	243
1906	1,393.1	674,200	244
1907	1,160.8	665,400	289
1908	666.8	484,100	366
1909	782	406,400	262
1910	609.9	332,650	275
1911	226.1	109,890	245
1912	466.3	174,790	189
1912–1913	357.0	177,745	251
1913–1914	593.5	429,706	365
1914–1915	791.3	572,900	365
1915–1916	2,679.5	1,264,900	238
1916–1917	1,069.9	502,930	237
1917–1918	246.8	127,740	261
1918–1919	239.6	173,470	365
1919–1920	629	456,630	366
1920–1921	380.6	275,530	365
1921–1922	589.2	426,550	365
1922–1923	292.8	211,990	365
1923–1924	151.5	84,150	280
1924–1925	185.6	134,370	365
1925–1926	150.4	108,880	365
1926–1927	334.4	242,110	365
1927–1928	272.7	198,000	366
1928–1929	264.1	191,220	365
1929–1930	211.1	152,834	365
1930–1931	72.7	52,628	365
1931–1932	52.5	38,077	366
1932–1933	41.8	30,241	365
1933–1934	17.5	12,662	365
1934–1935	82.0	59,374	365
1937–1938	126.0	90,886	365

APPENDIX II

SOURCES OF POLLUTION

SOURCES OF POLLUTION

Table I

Red River tributaries in North Dakota showing distance of mouth above International Boundary, distance of municipalities discharging sewage above mouth of tributaries, population, and type of treatment, are shown in the following table.

Distances of cities above mouths of tributaries are roughly estimated. Many other cities with sewerage systems, located in the water shed, discharge sewage into dry-run coulees, sloughs, etc., which rarely, if ever, reaches any watercourse. Among these are Langdon (1,221), Larimore (979), Casselton (1,253), McVille (513), Hankinson (1,400), Lidgerwood (1,029), Finley, Cooperstown, Northwood, Milnor. Except for the Sheyenne, tributaries in North Dakota are intermittent, flowing only during spring and early summer.

Tributary	Miles Above Boundary	Municipality (1930 Pop.)	Miles Above Mouth of Tributary	Type System* Treatment Date of Installation
Pembina..........	2.8	Cavalier (850)	40	Comb. Septic tank
Pembina..........	2.8	Walhalla (700)	60	Comb. None
Park..............	67	Grafton (3,136)	24	Comb. P.C., S.S.D., Tr. Filt., Sl.B., 1936
Park..............	67	Park River (1,131)	50	Comb. Septic tank, 1916
Goose.............	203	Hillsboro (1,317)	15	Comb., None
Goose.............	203	Mayville (1,199)	50	Comb. Imhoff
Sheyenne..........	273	Enderlin (1,839)	95	Comb. Septic tank, 1929
Sheyenne..........	273	Harvey (2,200)	520	Comb., None
Sheyenne..........	273	Lisbon (1,650)	150	Comb. Sc., Imh. T. Tr.F., Sl.B., 1936
Sheyenne..........	273	Valley City (5,268)	230	Comb., Sc., Pr.S., Act. Sl., Sec.S.,S.S.D., S.B., 1934
Sheyenne..........	273	West Fargo Packing Plant	20	Sc., Pr.S., Tr.F., Sec.S., Tr.F., Fin.S., Grease Sep.

Table II

Red River tributaries in Minnesota showing distance of mouth above the International Boundary, distance of municipalities discharging sewage above mouth of tributaries, population, and types of treatment. Data submitted by Minnesota Department of Health.

Tributary	Miles Above Boundary	Municipality (1930 Pop.)	Miles Above Mouth of Tributary	Treatment
Two Rivers........	25	Hallock (869)	12	None
Two Rivers........	25	Lancaster (456)	30	Imhoff Tank
Snake River.......	70	Warren (1472)	30	Imhoff Tank
Middle River......	76	Argyle (700)	12	Septic Tank
Red Lake River ...	143	Crookston (6,321)	45	None
Red Lake River....	143	Red Lake Falls (1,386)	83	None—Plant Under Construction
Red Lake River....	143	Thief River Falls (4,368)	117	Primary settling trickling filter secondary settling sep.Sl.D. Chl.
Red Lake River....	143	Fosston (978)	123	None
Sand Hill River....	187	Fertile (800)	30	None
Sand Hill River....	187	Climax (239)	3	None
Marsh River.......	195	Ada (1,285)	26	Septic Tank
Wild Rice River....	205	Mahnomen (989)	118	None—Plant Under Construction
Wild Rice River....	205	Twin Valley (657)	82	None
Buffalo River......	250	Hawley (958)	36	None
Buffalo River......	250	Barnesville (1,279)	45	Primary Settl. T., Act. Sl., Reset.T., Chl.
Ottertail River.....	395	Fergus Falls (9,389)	56	Settl.T., Sep.Sl. D., Chl.
Ottertail River.....	395	Frazee (1,041)	141	None—Plant Under Construction
Ottertail River.....	395	New York Mills (667)	135	Imh.T., Tr.F., Reset.T.
Ottertail River.....	395	Perham (1,411)	129	Settl.T., Tr.F., Reset.T.
Mustinka River....	435	Wheaton (1,279)	7	None
Mustinka River....	435	Graceville (969)	20	Imhoff Tank
Mustinka River....	435	Elbow Lake (903)	40	Imh.T., Sept.T.
Mustinka River....	435	Herman (515)	30	None
Mustinka River....	435	Donnelly (309)	40	None
Pelican River......	451	Detroit Lakes (3,675)	46	Imhoff tanks, trickling filters, resettling tanks
Pelican River......	451	Pelican Rapids (1,365)	25	Imhoff tank, trickling filter, resettling tank

*Key Follows Table VI

Table III

Municipalities in North Dakota with Sewerage Systems Discharging into the Red River of the North

Municipality	Population 1930	Miles above International Boundary	Treatment Units
Fairmount (Bois de Sioux).	611	430	Comb. Septic tank
Abercrombie	242	367	None
Wahpeton	3,136	395	Comb.,Pri.C., Tr.Filt.Scr., S.S.D., Sl.B., Sec.C. (None prior to Sept. '39)
Fargo	28,619	286.5	Comb., G.C., Det., P.C., Tr.F., S.S.D., Sl.B., 1936
State Mill & Elevator	......	140.8	None
Northern Packing Co.	......	140.7	None
Grand Forks	17,112	140.5	Comb., Sc., P.C., Ch.P., Sec.C., Cl., 1936

Table IV

Municipalities in Minnesota with Sewerage Systems Discharging into the Red River of the North

Municipality	Population 1930	Miles above International Boundary	Treatment Units
Breckenridge	2,264	395	None
Wolverton	206	323	Imhoff tank
Moorhead	7,651	292	Settling tank, trickling filter, resettling tanks
Halstad	535	220	None
East Grand Forks	2,922	142	None
East Grand Forks American Crystal Sugar Company	142,000*	141.2	Lagoons

*Estimated population equivalent of wastes, Report 1931-32-33. Plant operates two and one-half to three months starting in September.

Key for Sewage Treatment

Comb. — Combined storm and sanitary sewerage systems.
Sc. — Screen.
P.C. — Primary Clarification.
Pr. S. — Primary Settling.
S.S.D. — Separate Sludge Digestion.
Tr.F. — Trickling Filter.
Sl. B. — Sludge Beds.
Imh. T. — Imhoff Tank.
Act. Sl. — Activated Sludge.
Sec. S. — Secondary Settling.
Fin. S. — Final Settling.
Chl. — Chlorination.
Reset. T. — Resettling Tank.
Ch. P. — Chemical Precipitation.

Table V

INDUSTRIAL AND MUNICIPAL WASTES DISCHARGED DIRECTLY INTO THE RED RIVER

Source	Miles Above International Boundary	Population Equivalent	Quantity Gal./Day	Per Cent Treatment	Average 5-day B.O.D. 20°C. P.P.M.	Average 5-day B.O.D. Lbs./Day
Moorhead, Minnesota	292	12,500**	....	85	....	306*
Fargo, North Dakota	286 ½	33,109	1,960,000	77.45	69	1,126.6
Halstad, Minnesota	220	535	....	None	....	62***
East Grand Forks, Minnesota	142	2,922	138,609	None	595.5	687.6
American Crystal Sugar Co., East Grand Forks, Minnesota	141 ¼	......	5,706,963****	Retention in Lagoon	513.5	25,412
North Dakota State Mill Grand Forks, North Dakota	140 ¾	......	42,871****	None	237	72.7
Grand Forks, North Dakota	140 ½	19,878	830,000	38.3	194.1	1,342
Northern Packing Co., Grand Forks, North Dakota	140 ¼	......	62,119****	None	656.2*	335*

*Calculated from equivalent population using .163 lb. per capita or 68% of .24. (Combined sewer)
**Taken from 1931, 32, 33 Report on Red River of the North Pollution Survey.
***Calculated from equivalent population using .115 lbs. per day per capita or 68% of .17. (Separate sewer)
****Average calculated from sampling data.

APPENDIX III

Theoretical B.O.D. Calculations

APPENDIX III

MATHEMATICAL FORMULATION OF THE RATE OF B.O.D.

One of the most important problems of this study was the determination of oxygen demands under conditions of ice coverage. Several samples, taken from the river at different stations, were incubated at 0° and 2°C. over long periods of time in order to provide data for the formulation of the rate constants at these temperatures. It was found after several tests that the carbonaceous, or first stage B.O.D., was practically completed after about 30 days. For this reason the first stage unimolecular curves developed were assumed to hold only for the first 30 days. The first stage B.O.D. is represented by the well-known oxidation formula, $\log \frac{L_a}{L_t} = kt$

where L_a = the first stage B.O.D.
X_t = amount reacted at time t.
$L_t = L_a - X_t$ = amount left to react at time t.
k = reaction velocity constant.
t = time in days.

The Thomas Slope Method* of analysis was used in determining the values of k and L and the following results were obtained:

Jan. 5, 1940 0°C.

Sta.	k	L
2	.0387	7.52
3	.0431	7.31
4	.0381	13.81
5	.0180	39.59
Ave.	.0340	

Feb. 6, 1940 0°C.

Sta.	k	L
6A	.0338	7.65

Jan. 11, 1940 2°C.

Sta.	k	L
1	.0334	4.81
2	.0491	8.03
3	.0321	12.97
4	.0357	5.55
5	.0288	5.77
6A	.0416	4.14
Ave.	.0368	

It was found by this method that samples taken at stations below Grand Forks gave an average value of k of .034 at 0°C. and a value of .037 for 2°C. Insufficient data were available to make an accurate determination of k at 20°C. Since the 20°C. value of k was necessary in converting 20°C. data to 0°C. data, an attempt was made to determine k at 20°C. empirically from the data, by cut and try methods. A value of .08 was found to give the best general fit to the data and has been used in the computations. This value is lower than the generally accepted figure of 0.1 for sewage dilutions at 20°C.

*S.W.J. May 1937, Vol. IX, No. 3, page 425.

Since the calculated values of k at 0° and 2°C. were slightly lower than what is commonly experienced with domestic sewage, it would seem likely, therefore, that the 20° value would also be lower. Values ranging from .062 to .08 were obtained at 20°C. from packing plant wastes and Grand Forks sewage during the months of January, February and March 1939. The rate constant of a contributing waste should influence to some degree the rate constant of the stream. As a result a uniformity of k for different rivers or for different reaches of the same river should not be anticipated.

The Thomas Slope method* of analysis was used in determining the value of k on one sample taken in July 1940 from a point below Grand Forks. No definite conclusions may be drawn from the results of one analysis but if the value of .132 which was found for k at 20°C. is any indication of summer conditions it may be expected that quite different types of wastes and organisms were being encountered.

The following formula is an accepted relationship between rate constants at different temperatures:

$$k_T = k_O\ \Theta^{(T-O)}$$

For this specific case:

$$k_{20} = k_0\ \Theta^{(20-0)}$$

when $k_{20} = .08$

and $k_0 = .034$

$\Theta = 1.044$ (This same value of Θ also holds for $k_0 = .034$ and $k_2 = .037$)

For a 5-day B.O.D. of 1.00 at 20°C. and a k of .08 the following value of L_a was found:

$$\log \frac{L_t}{L_a} = -kt$$

$$\log \frac{L_t}{L_a} = -.08 \times 5 = -.40$$

$$\frac{L_t}{L_a} = .398$$

$$\% \text{ of total} = 100(1-.398) = 60.2$$

$$L_a = L_{20} = \frac{1.0}{.602} = 1.66$$

The ultimate B.O.D. at 20°C. may then be converted to 0°C. by the following formula of Streeter & Phelps:

$$L_T = L_{20}\ [1 + 0.02(T-20)]$$

$$L_O = 1.66\ [1 + 0.02(0-20)]$$

$$L_O = 1.66 \times .6 = .996 \text{ (say 1.00)}$$

From the above it may be seen that the ultimate first stage B.O.D. at 0°C. is equal to the 5-day 20°C. B.O.D. of this river water. Knowing this relationship it was possible to set up the attached table of 0° B.O.D.'s corresponding to a 5-day 20°C. B.O.D. of 1.0 p.p.m.

As stated before the unimolecular first stage curve is taken here to represent the B.O.D. only for the first 30 days of oxidation; after this time the nitrification or second stage oxidation begins to show its effect. The unimolecular type of curve has been found to apply to the second as well as the first stage of oxidation. Streeter*, in his analysis of several samples of the Illinois River water, incubated by the Sanitary District of Chicago during 1927-30, found the nitrifica-

*Mathematics shown on page 193.

tion or second stage rate of reaction to be approximately one-third the first stage rate of reaction. As before, the amount reacting in any time **t** is a function of the ultimate second stage B.O.D. The routine laboratory determination of this ultimate value, of course, was not a practical procedure. Therefore, in order to calculate the B.O.D. for any period over 30 days, a relationship between the 5-day 20°C. B.O.D. and the ultimate second stage B.O.D. at 0°C. was necessary.

An inverse relationship was found between the ultimate first stage B.O.D. (L_a) and the probable ultimate second stage B.O.D. (L_b). As an example, in the event of an L_a of 10 p.p.m. the total 50-day B.O.D. was found to be approximately 1.3 p.p.m. in excess of the first stage value for the same number of days, while an L_a of 3 p.p.m. resulted in the total B.O.D. of approximately 1.7 p.p.m. in excess of the first stage at 50 days.

The following formula represents one form of the unimolecular expression of the nitrogenous stage of oxidation beginning at 30 days:

$$X_{tb} = L_b \ (1\text{-}10^{-k(t-30)}$$

The value of X_{tb} must be added to the first stage B.O.D. for the corresponding number of days to obtain the total B.O.D. at any time. It may be seen that the formula holds only for positive values of (t-30). A value of .012 for k_b at 0°C. was found to give the best general fit to the data and is in accord with the finding that k_b is approximately one-third k_a.

By means of this formula the 50-day X_{tb} values of 1.3 p.p.m. and 1.7 p.p.m. mentioned above were found to give ultimate second-stage B.O.D.'s of 3.06 p.p.m. and 4.00 p.p.m. respectively for corresponding ultimate first-stage 0°C. B.O.D.'s of 10 p.p.m. and 3 p.p.m. The following empirical equation was developed in order that L_b value in the formula above may be given in terms of L_a:

$$L_b = C - x \log L_a$$

Where $C = 4.86$

$x = 1.8$

It is believed that the constant and exponent in this equation would vary considerably for different rivers containing various types of wastes. Referring again to Streeter's paper on Natural Oxidation, the following values were found for L_a and L_b on Illinois River samples:

Sampling Point	L_a	L_b
Lockport	20.5	20.5
Morris	10.2	18.5
Marseilles	9.8	15.0
Peru	7.9	13.0
Henry	4.8	7.7

By plotting these values on semi-log paper and drawing the line of best fit, the constant (C) is equal to the value of L_b where L_a equals

*S.W.J. Vol. VII, No. 3, March 1935.

unity, with due respect to sign. The value of (x) is equal to the reciprocal of the slope of the line, also with due respect to sign. For the above data C = -7.8 and x = -23.2. The resulting equation is therefore:

$$L_b = 23.0 \log L_a - 7.8$$

Following is a comparison between the observed values of L_b and the calculated values using the formula above:

Station	Calculated	Observed
Lockport	22.4	20.5
Morris	15.4	18.5
Marseilles	15.0	15.0
Peru	12.8	13.0
Henry	7.9	7.7

Insufficient data are available for definite determinations of the constants in this relationship. However, the trend is apparent even though the values used for this study were determined empirically. The resulting second stage formula used in this study in terms of the first stage ultimate B.O.D. is as follows and is shown graphically in Figure 25.

$$X_{tb} = (C - x \log L_a)\,(1 - 10^{-k(t-30)})$$

$$\text{Where } C = 4.86$$
$$x = 1.8$$
$$k = .012$$

$$\text{or } X_{tb}\ (4.86 - 1.8 \log L_a)\,(1\text{-}10^{-.012(t-30)})$$

Combining the first and second stage formula, the following discontinuous equation was obtained which holds for positive values of (t — 30) and 0°C:

$$\text{Total B.O.D.} = L_a\,(1\text{-}10^{-.034t}) + (4.86 - 1.8 \log L_a)\,(1\text{-}10^{-.012(t-30)})$$

For negative values of (t-30) the latter portion of the equation is dropped and the unimolecular expression for first stage oxidation remains. This formula is used with the full knowledge that the proposed logarithmic relationship between the first and second stage ultimate B.O.D.'s may not hold for all types of wastes or river water. It closely approximates actual observed data of this study and its application to Illinois River data has been shown. However, it should not be applied without reservation in other studies.

APPLICATION OF MATHEMATICAL FORMULATION

In analyzing the data, it was found that the ultimate 0°C. B.O.D. closely approximated the 5-day 20°C. B.O.D. in most cases. For Station 5 on January 11, 1940, the 5-day 20°C. value was found to be 4.34 p.p.m. The 31-day value read from the table should be .911 x 4.34 or 3.95 p.p.m. As the first stage curve holds only to 30 days the second stage oxidation must be taken into consideration. From Figure 25 the 31 day value of X_{tb} for an L_a of 4.34 p.p.m. is .09 p.p.m. This added to the 31-day first stage value of 3.95 gives a total of 4.04 p.p.m. Similarly for 41 days the first stage value is found to be .959 x 4.34 or 4.16 p.p.m. From the graph 41 days gives

an X_{tb} of .96 p.p.m. for an L_a of 4.34 p.p.m. The resulting total B.O.D. is 4.16 plus .96 = 5.12 p.p.m.

The above values of 4.04 p.p.m. and 5.12 p.p.m. at 0°C. compare favorably with the 2°C. values, which were actually determined, of 4.44 p.p.m. and 5.15 p.p.m. respectively.

If, with a flow of 200 c.f.s. during any one period, the time of flow from Station 5 to Lake Winnipeg was 31 days, the oxygen utilized would be:

200 x 5.4 x 4.04 = 4363 lbs. oxygen
(Note: 5.4= lbs.0_2/day/p.p.m. B.O.D. / c./f./s.)

If a flow of 100 c.f.s. required 41 days, the oxygen utilized would be: 100 x 5.4 x 5.12 = 2765 lbs. oxygen

The above procedure was used throughout this report in determining the oxygen utilized to Lake Winnipeg for the river stations below Grand Forks. The condition between Fargo and Grand Forks presents a slightly different problem due to the fact that considerable aeration is obtained by means of the Grand Forks dam. It is therefore necessary to provide sufficient oxygen at Fargo to satisfy the oxygen demand only to Grand Forks. For this reason 0°C. B.O.D.'s above Grand Forks were calculated in terms of pounds of oxygen required for time of flow to Station 6. The flow may, however, be in excess of the amount required for this portion of the river because of the greater requirements at and below Grand Forks.

EXAMPLE ILLUSTRATING USE OF THOMAS SLOPE METHOD**

Station 6-A 26°C. 7-10-40

Days t	Δt	B.O.D. y	Δy	y′	yy′	y²
0		0				
	1		2.46			
1		2.46		*1.62	3.985	6.052
	1		.78			
2		3.24		.70	2.268	10.498
	1		.62			
3		3.86		.70	2.702	14.900
	1		.78			
4		4.64		.545	2.529	21.530
	1		.31			
5		4.95		.245	1.213	24.502
	1		.18			
6		5.12 (not inc. in sum)				
Total		19.15		3.810	12.697	77.482

$$*y'_n = \frac{(y_n - y_{n-1})\left(\frac{t_{n+1} - t_n}{t_n - t_{n-1}}\right) + (y_{n+1} - y_n)\left(\frac{t_n - t_{n-1}}{t_{n+1} - t_n}\right)}{t_{n+1} - t_{n-1}}$$

$$= \frac{(\Delta y)_{n-1}\left(\frac{\Delta t_{n+1}}{\Delta t_{n-1}}\right) + (\Delta y)_{n+1}\left(\frac{\Delta t_{n-1}}{\Delta t_{n+1}}\right)}{(\Delta t_{n-1}) + (\Delta t_{n+1})} = \frac{2.46 + 0.78}{2} = 1.62$$

**S.W.J. May, 1937, Vol. IX, No. 3, p. 425, Thomas.

Normal Equations

$$na + b\Sigma y - \Sigma y' = 0$$

I $$5a + 19.15b - 3.810 = 0$$

$$a\Sigma y + b\Sigma y^2 - \Sigma yy' = 0$$

II $$19.15a + 77.482b - 12.697 = 0$$

$$I \times \frac{19.15}{5} = III = 19.15a + \frac{19.15^2 b}{5} - \frac{3.810 \times 19.15}{5} = 0$$

$$II - III \; (77.482 - \frac{19.15^2}{5})b = 12.697 - \frac{3.810 \times 19.15}{5}$$

$$b = \frac{12.697 - 14.592}{77.482 - 73.345} = -\frac{1.895}{4.137}$$

$$-b = .458 = K$$

$$k = \frac{.458}{2.3026} = .1989$$

$$a = \frac{1}{n}\Big[-b \,\Sigma\, y + \Sigma\, y' \Big]$$

$$= \tfrac{1}{5}\,[\,.458 \times 19.15 + 381\,] = \tfrac{1}{5}\,(8.77 + 3.81) = 2.516$$

$$L = \frac{a}{K} = \frac{2.516}{.458} = 5.493 \text{ p.p.m.}$$

Data for Plotting Unimolecular Curves

First Stage Oxidation

General Formula: $\text{Log}\,\frac{L}{L_t} = kt$

$$\text{Log } 5.493 - \text{Log } L_t = .1989t$$

$$.73981 - \text{Log }(5.493 - \text{B.O.D.}) = .1989t$$

$$\text{Log }(5.493 - \text{B.O.D.}) = .7398 - .1989t$$

Days	kt	$\frac{L}{L_t}$	L_t	X_t
1	.1989	1.581	3.474	2.019
2	.3978	2.499	2.198	3.295
3	.5967	3.952	1.390	4.103
4	.7956	6.246	.879	4.614
5	.9945	9.874	.556	4.937
6	1.1934	15.610	.352	5.141
7	1.3923	24.682	.223	5.270
8	1.5912	39.012	.141	5.352

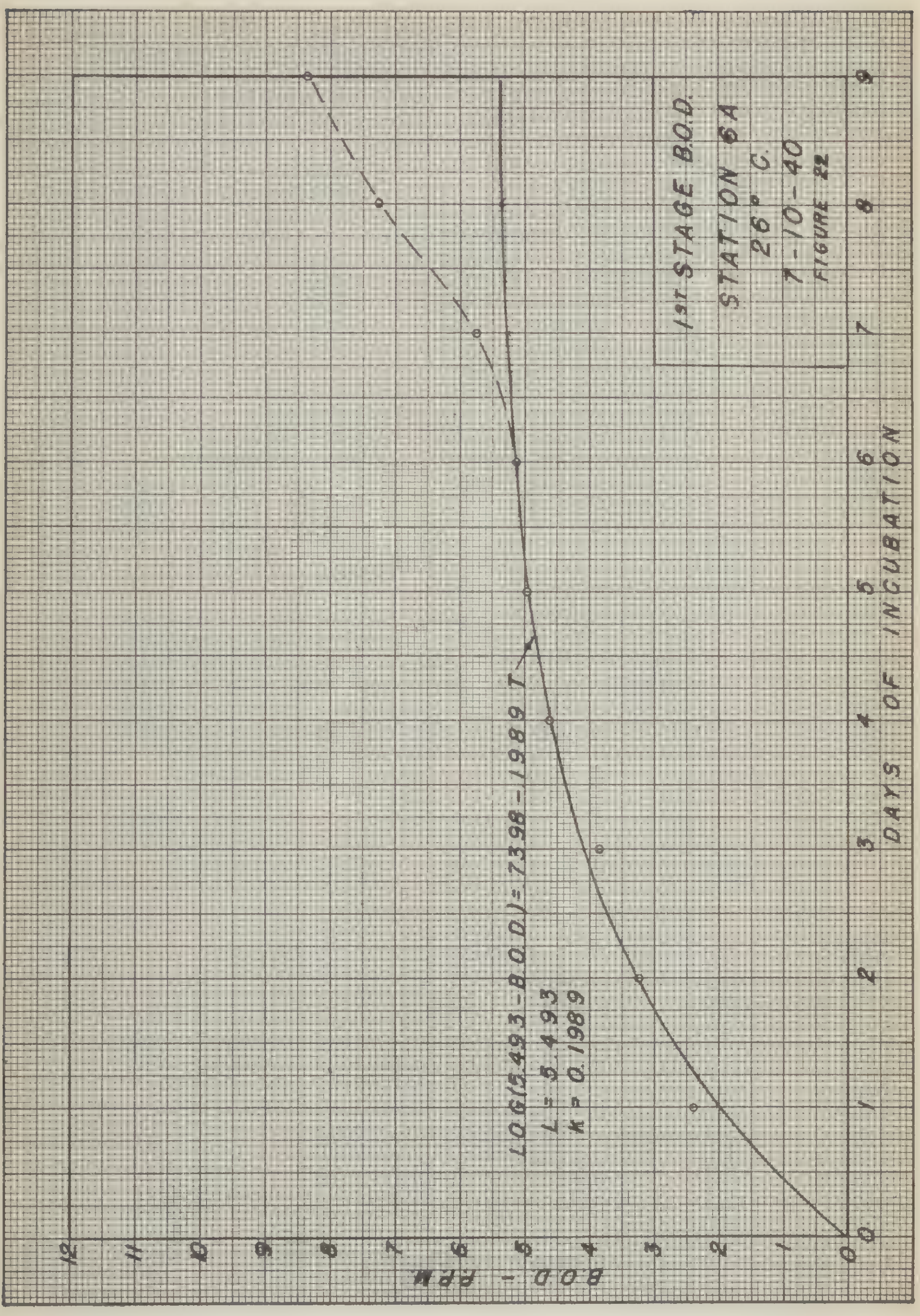
To Obtain k @ 20°C:

$$k_{26} = k_0\ \Theta^{26}$$

$$\frac{.1989}{.034} = \Theta^{26} = 5.85$$

$$\Theta = 5.85^{.0377} = 1.070$$

$$k_{20} = .034 \times 1.070^{20} = .132$$

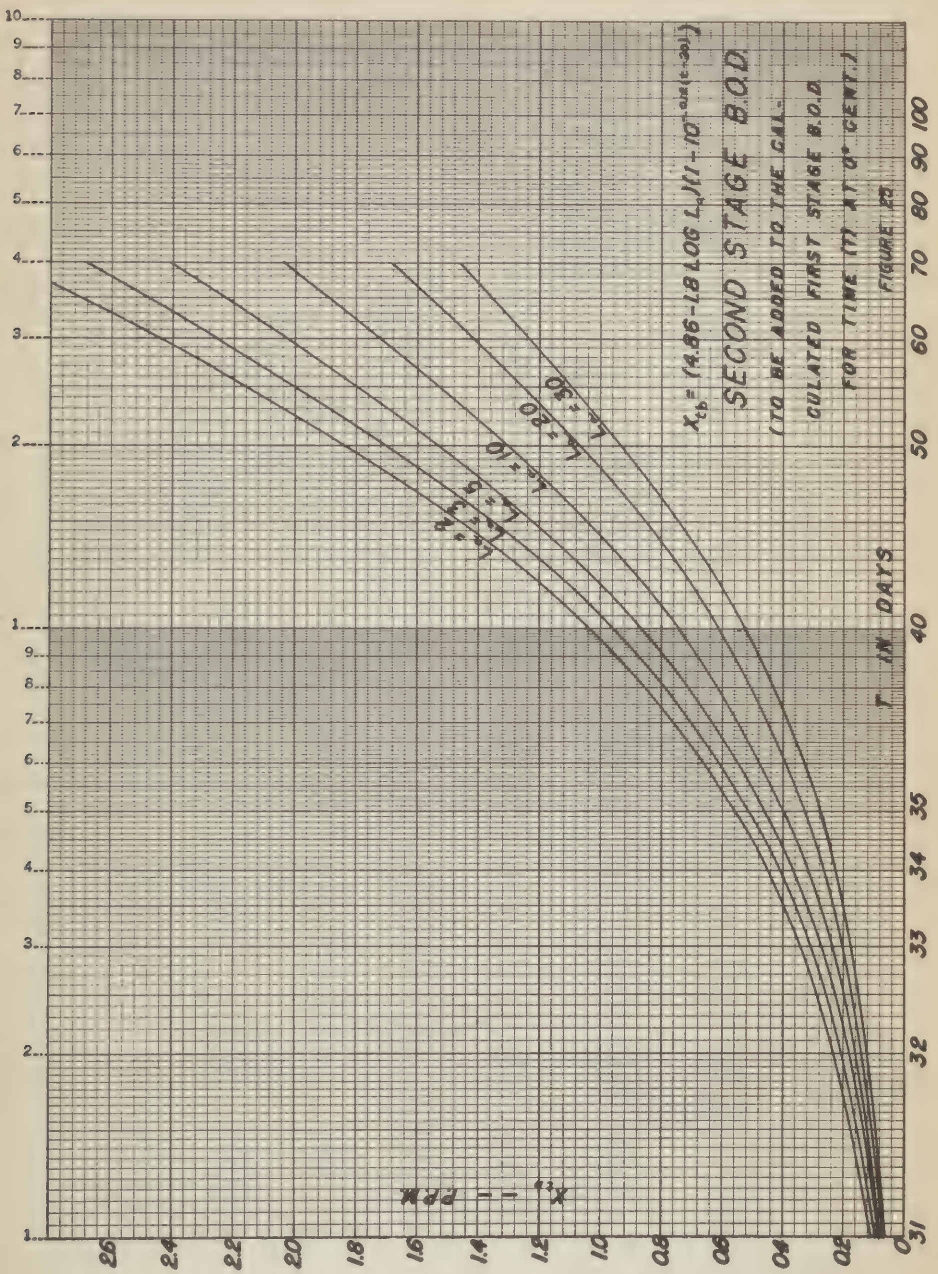

1st STAGE B.O.D.
STATION 6A
26° C.
7-10-40
FIGURE 22
LOG(5.493-B.O.D.)=.7398-.1989 T
L = 5.493
K = 0.1989
BOD - PPM
DAYS OF INCUBATION

CONVERSION TABLE

For converting 5-day 20°C. B.O.D. to 0°C. B.O.D.
for any stated number of days.

$\log \frac{L_t}{L} = -kt$ k = 0.034 Temperature = 0°C.

Days	$-\log \frac{L_t}{L}$	$\frac{L_t}{L}$	B.O.D.—0°C. % of Total First Stage	B.O.D. at 0°C. for 5-day 20°C. B.O.D. of 1.0 p.p.m.
2	.068	.855	.145	.145
4	.136	.731	.269	.269
5	.170	.676	.324	.324
6	.204	.625	.375	.375
8	.272	.535	.465	.465
10	.340	.457	.543	.543
12	.408	.391	.609	.609
14	.476	.334	.666	.666
16	.544	.286	.714	.714
18	.612	.244	.756	.756
20	.680	.209	.791	.791
22	.748	.178	.822	.822
24	.816	.153	.847	.847
26	.884	.131	.869	.869
28	.952	.112	.888	.888
30	1.020	.095	.905	.905
35	1.190	.065	.935	.935
40	1.360	.044	.956	.956
45	1.530	.030	.970	.970
50	1.700	.020	.980	.980
60	2.040	.009	.991	.991
70	2.380	.004	.996	.996


SECOND STAGE B.O.D.
(TO BE ADDED TO THE CAL-
CULATED FIRST STAGE B.O.D.
FOR TIME (T) AT 0° CENT.)
T IN DAYS
PPM

LONG RANGE BIOCHEMICAL OXYGEN DEMAND DATA
Samples Collected January 11, 12, 1940

Sample From Station	20°C. Days of Incubation					2°C. Days of Incubation							
	5	10	16	20	31	5	10	16	20	31	41	51	60
1	4.84	10.44	.....	.....	.....	1.59	2.38	4.26	3.89	4.66	5.82	6.75	....
2	9.52	13.98	20.32	22.20	.....	3.77	5.20	6.48	7.09	8.03	8.93	9.56	....
3	11.18	11.12	24.38	25.96	.....	6.06	7.55	10.61	10.86	12.85	13.74	....	....
4	5.34	8.20	12.00	15.04	16.80	1.99	2.95	4.31	4.56	5.19	5.68	6.52	....
5	4.34	6.65	11.80	12.15	15.20	1.85	2.73	3.81	4.65	4.44	5.15	5.83	....
6A	5.20	4.30	7.20	10.25	12.95	1.78	2.44	3.20	4.98	3.99	4.90	6.01	....
8	2.80	7.14	14.98	.....	.....	.90	1.29	1.92	1.84	2.22	2.99	3.83	4.71
9	6.75	21.53	29.87	.....	.....	1.48	1.99	3.20	3.82	4.85	7.10	9.38	....
10	5.85	15.36	39.03	.....	.....	2.09	3.41	3.22	3.72	4.79	6.30	8.22	....
11	28.90	68.67	115.52	.....	.....	10.46	19.68	24.56	26.41	30.16	....	....	....
12	3.58	6.12	10.00	.....	.....	1.11	1.93	2.75	2.99	3.48	4.65	4.94	....

LONG RANGE BIOCHEMICAL OXYGEN DEMAND DATA

Sample From Station	Date of Coll.	5-day B.O.D. at 20°C.	Days of Incubation at 0°C.							
			5	10	15	20	30	39	44	59
1	2-6-40	2.13	.09	1.63	.87	1.50	2.98	....	....	....
2	2-6-40	1.87	.14	.59	.89	1.80	1.86	2.48	....	....
3	2-6-40	1.40	.05	.30	.60	1.91	2.53	....	....	....
4	2-6-40	1.68	.10	.57	.72	1.36	1.80	....	....	....
5	2-6-40	1.84	.27	.92	1.15	1.85	2.38	....	....	....
6A	2-6-40	5.70	2.51	4.14	5.07	5.98	6.86	....	....	....
8	2-7-40	22.68+	1.89	8.80+	17.47+	....	....	....	....	....
9	2-7-40	12.45	2.80	4.32	6.32	7.65	10.03	....	....	....
10	2-7-40	10.51	1.34	3.42	5.56	6.84	8.96	9.72	....	....
11	2-7-40	24.49	4.80	10.96	16.56	20.22	25.36	....	....	....
12	2-7-40	2.14	.45	1.25	1.71	3.05	2.93	4.70	....	....
J	2-7-40	1.73	.21	.56	2.02	1.48	1.65	2.02	....	....
1	1-5-40	2.95	.38	1.34	2.70	2.20	....	....	....	....
2	1-5-40	6.89	2.50	4.33	5.58	5.66	6.85	....	7.75	9.35
3	1-5-40	7.23	2.58	4.55	7.21	5.95	6.84	....	....	....
4	1-5-40	13.76	4.20	8.21	9.91	11.02	14.06	....	....	....
5	1-5-40	23.85	6.88	13.00	18.02	22.02	....	....	....	....

APPENDIX IV

STREAM FLOW REQUIREMENTS

APPENDIX IV

STREAM FLOW REQUIREMENTS

During open water periods the oxygen content of the stream is dependent upon the rate of oxygen use (k_1), the rate of reaeration (k_2), and the ultimate first stage B.O.D. (L_a) of the river immediately below the point of pollution. Assuming that the dilution water or the stream above the point of pollution has a B.O.D. of zero, it follows that the ultimate B.O.D. of the stream (L_a) times the total stream flow is equal to the ultimate B.O.D. of the sewage times the sewage flow. For example, during the summer months the Fargo-Moorhead area discharges 2.7 m.g.d. of sewage containing 1400 lbs. of 5 day 20°C. B.O.D. per day. This results in a 5 day 20°C. B.O.D. of 62.1 p.p.m. or an ultimate first stage B.O.D. of 91.3 p.p.m.* A flow of 2.7 m.g.d. equals 4.18 c.f.s. Therefore, where c equals the required stream flow for dilution purposes and L_a equals the ultimate first stage B.O.D. of the stream, immediately below the point of pollution,

$$L_a\ (c + 4.18) = 4.18 \times 91.3$$

$$\text{or } L_a = \frac{4.18 \times 91.3}{(c + 4.18)} = \frac{381.6}{(c + 4.18)} \quad \text{.......... (1)}$$

Immediately below the point of pollution the dissolved oxygen deficit (D_a) is equal to the ratio of the sewage flow to the total flow, times the saturation value, assuming the dilution water is saturated and the sewage is entirely depleted of dissolved oxygen. For the conditions mentioned above

$$D_a = \frac{4.18}{c + 4.18} \times 9.17$$

$$D_a = \frac{38.33}{(c + 4.18)} \quad \text{.......... (2)}$$

From equations (1) and (2)

$$\frac{D_a}{L_a} = \frac{38.33}{(c + 4.18)} \times \frac{381.6}{c + 4.18} = 0.10$$

*Based on a value of k equal to 0.1 for summer conditions.

Fair* developed the following equations which may be used to advantage in determining the required flow (c) for dilution purposes:

$$k_1t_c = \frac{1}{(f-1)} \log \left\{ f \left[1 - (f-1)\frac{D_A}{L_a} \right] \right\} \quad (3)$$

$$D_c = \frac{L_a}{f} (10^{-k_1t_c}) \quad (4)$$

or $$L_a = D_c \times f \times 10^{-k_1t_c} \quad (4a)$$

Where k_1 = B.O.D. rate of constant.

t_c = time in days of miximum dissolved oxygen deficit.

f = k_2k_1 = self-purification constant, taken as 1.3 for sluggish streams at 20°C.

D_c = allowable deficit = 9.17 — 3.00 = 6.17 at 20°C.

Continuing the analysis of the example taken above and applying equation (3):

$$k_1t_c = \frac{1}{1.3-1} \log \left\{ 1.3 \left[1 - (1.3-1)\ 0.10 \right] \right\}$$

$$= 3.33 \quad \log \cdot 1.261 = 0.338$$

Substituting in equation (4a)

$$L_a = 6.7 \times 1.3 \times 10^{0.338} = 17.48 \text{ p.p.m.}$$

Substituting in equation (1)

$$17.48 = \frac{381.6}{c \times 4.18}$$

$$c = \frac{381.6}{17.48} - 4.18 = 17.63 \text{ c.f.s.}$$

Applying the same analysis to the wastes from the West Fargo Packing Plant, on the basis of 98% treatment the required flow was 2.12 c.f.s., giving a total of 19.75 c.f.s. An arbitrary value of 20% has been added to all calculated summer flows to compensate for the assumptions that all dilution water has a B.O.D. of zero and that no pollution enters between major points of pollution. It is known that waters carried in a natural channel will pick up some material which will exert a demand, the magnitude of which is difficult to estimate. Adding 20% to the flow of 19.75 c.f.s. the resulting required flow for dilution purposes at Fargo and West Fargo is 23.7 c.f.s.

The water consumption of the Packing Plant and the Fargo area, 1.0 and 9.0 c.f.s. respectively, must be added to the above requirement giving a total of 33.7 c.f.s. during summer months.

The allowable critical deficit is dependent upon the oxygen saturation value and will vary inversely with respect to temperature. The self-purification constant (f) will also change with temperature according to the following relationship:

$$f_T = f_{20} \times 0.970^{(T-20)}$$

*S.W.J.—May, 1939, Vol. II, No. 3, p. 451.

The foregoing analysis is based on relationships developed in connection with other studies, in the absence of algal activity and sludge deposits. As both of these interfering factors exist in the Red River, it was impossible to determine accurately the self-purification constants. It is believed that the calculated flow, as shown, is ample for sewage dilution purposes during average existing summer conditions below Fargo.

Similar analyses were made for other portions of the River for various seasons and the results are shown in Table I.

The average summer water temperature was taken as 20°C. which closely approximates the water temperatures observed during the months of June to September inclusive. During the month of October, the average temperature was taken as 7°C. The increased flow requirement at Grand Forks for this month is a result of beet sugar plant operations. The magnitude of this increase, however, is not exactly proportional to the increased pollution load as the rate of oxidation is slower and the dissolved oxygen saturation value of the water is greater at lower temperatures.

Flows as shown in Table I are for existing summer and winter conditions and also for summer and winter conditions in the event of 85 per cent treatment of all municipal and industrial wastes. Under ice coverage conditions no natural pollution was assumed to enter the stream between major sources of pollution. The flow at a municipality was calculated to satisfy the demand of 15 per cent of the untreated waste to the next source of pollution. For example, during the winter critical period, the B.O.D. of 15 per cent of the untreated wastes at Lisbon plus the B.O.D. remaining in the stream from upper sources must be satisfied for the time of travel to Fargo. That portion of the B.O.D. which did not have time to oxidize was then added to 15 per cent of the untreated contribution from the Fargo area and the demand for the time of travel to Grand Forks calculated.

The same method was followed for the Grand Forks area: the remaining unoxidized portion of the wastes from Fargo and Crookston were added to 15 per cent of the untreated contribution at Grand Forks. The oxygen requirement of this total was then calculated for the time of flow to Lake Winnipeg. A trial and error method of analysis was employed as the time of flow between two points varies with the magnitude of flow. For this reason the correct flow had to be assumed before an accurate oxygen demand between two points could be determined.

All winter calculations were made on a basis of 3 p.p.m. of oxygen available in the dilution water for the oxidation of wastes. The dissolved oxygen content necessary for the maintenance of normal fish life was considered as approximately 3 p.p.m. and this value has been set as the allowable minimum residual. The total minimum oxygen requirement at a point of dilution is, therefore, 6 p.p.m.

The winter "Existing Conditions" in Table I were derived from average observed conditions in the River, while the summer "Existing Conditions" and the 85 per cent treatment values were based on the measured amount of wastes discharged into the stream during the time of the survey. The average monthly flow requirements for these winter and summer conditions are shown on the attached graphs. No attempt was made to forecast industrial expansion and future population.

Because of open water conditions, flow requirements during the summer are not accumulative. No supplemental flow from the Red Lake River or other tributaries was assumed since the flow in these streams have approached zero and dependable flow is therefore not assured. For this reason all flow requirements must be provided at Fargo. The flow requirements for the section of the River from Fargo to Lake Winnipeg were based on the maximum demand whether it was incurred at Fargo or Grand Forks.

Stream flows for other standards of stream sanitation based on oxygen content may be determined by the same procedure as outlined above. A summary of stream flow requirements is presented in Table I following:

Table I

FLOW REQUIREMENTS — C.F.S.

(Cumulative Flows At Locations Shown)

LOCATION	Conditions with Existing Treatment of Wastes			Conditions with 85% Treatment of Wastes		
	Summer	October	Winter	Summer	October	Winter
Fargo	33.7	12.2	129.	47.6*	17.8*	145*
Grand Forks Without beet sugar wastes	46.5	......	253.	12.9	......	112
Grand Forks With beet sugar wastes	......	177	1081.	......	23.4	305

In the foregoing discussion the flow necessary for the formation of ice has not been considered. For the stretch of river from Fargo to Lake Winnipeg, at least 160 c.f.s. for a period of one month would be necessary to form an ice cover 2 feet thick. This requirement may coincide with the highest winter requirement (during operation of beet sugar plant).

During the process of freezing a large portion of the impurities are expelled from the ice, leaving them in solution or suspension

*Larger demand than with existing treatment of wastes because of the 98% treatment provided at present by West Fargo Packing Plant.

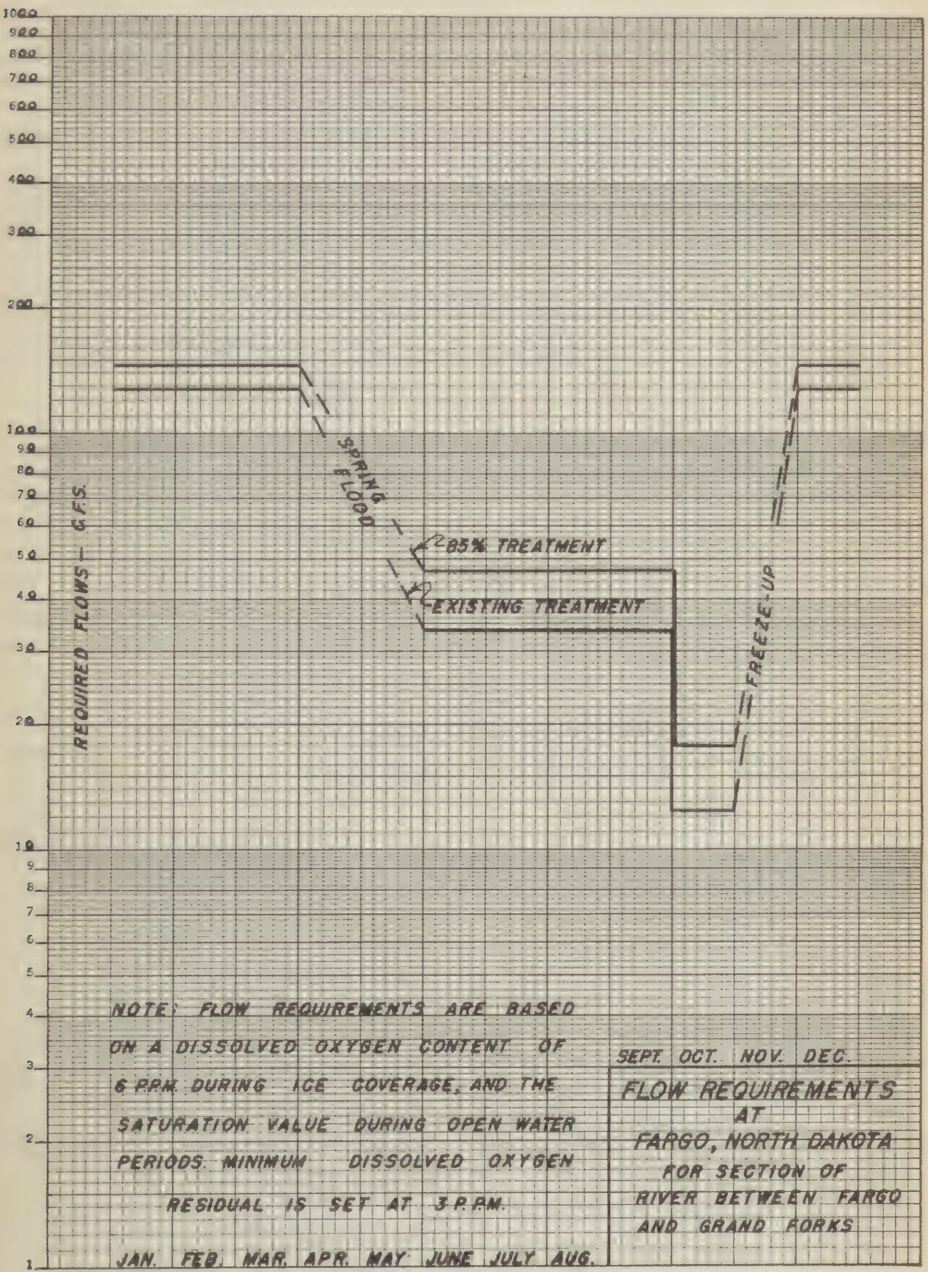
in the water below. This seems true for dissolved oxygen. If an original dissolved oxygen content of 6 p.p.m. is assumed, at least 8 p.p.m. additional could be absorbed before saturation is obtained. During operation of the Beet Sugar Plant and with 85% treatment of all wastes 305 c.f.s. are necessary for dilution purposes at Grand Forks under ice coverage. If 160 c.f.s. are used to form ice, the resulting flow at Lake Winnipeg may decrease to 145 c.f.s. According to the above theory the total oxygen content of the stream in pounds would still be the same along the entire stretch of the river as it would be if 305 c.f.s. were flowing. On a basis of 3 p.p.m. of oxygen remaining at Lake Winnipeg 305 c.f.s. would contain 4941 pounds per day. This same amount of oxygen contained in 145 c.f.s. would represent 6.3 p.p.m. which is actually more than necessary at Lake Winnipeg.

It would be difficult to calculate the requirements on the basis of the analysis just preceding because of other interfering factors. Bubbles are frequently noticed in the ice; an abundance of these result in "frosty" ice. Considerable oxygen must be entrained in this manner. Also the stream frequently flows over the ice and freezes to form a layer of ice over the original ice cover.

The volume of water actually contained on a certain stretch of river is also an important factor. The ice formed may not be a large percentage of the volume of a slowly moving mass of water although the number of cubic feet of ice formed per second may be a large percentage of the flow. It is doubtful, therefore, whether continued freezing for only one month is ample to decrease the flow at Lake Winnipeg in an amount equal to the average rate of freezing.

The entrainment of oxygen in the ice may necessitate an increase rather than a decrease in the flow requirements. If ice formation begins during a flow of 305 c.f.s. the channel capacity under 2 feet of ice will be considerably less. It has been shown above that the oxygen concentration of the water may be increased during the freezing process although the following month with no additional freezing 305 c.f.s. are again necessary. It may, therefore, be necessary to supply a large quantity of flow prior to freeze-up to insure channel capacity during the later winter months. The frequency with which streams have been observed to flow over previously formed ice indicates that consideration should be given to the establishment of adequate channel capacity, and to the influence of ice formation on the establishment of such channel capacity.

Because of the complications attending the calculation of stream flow requirements for the formation of ice, the effect of ice cover has not been taken into consideration except insofar as it precludes reaeration of the stream.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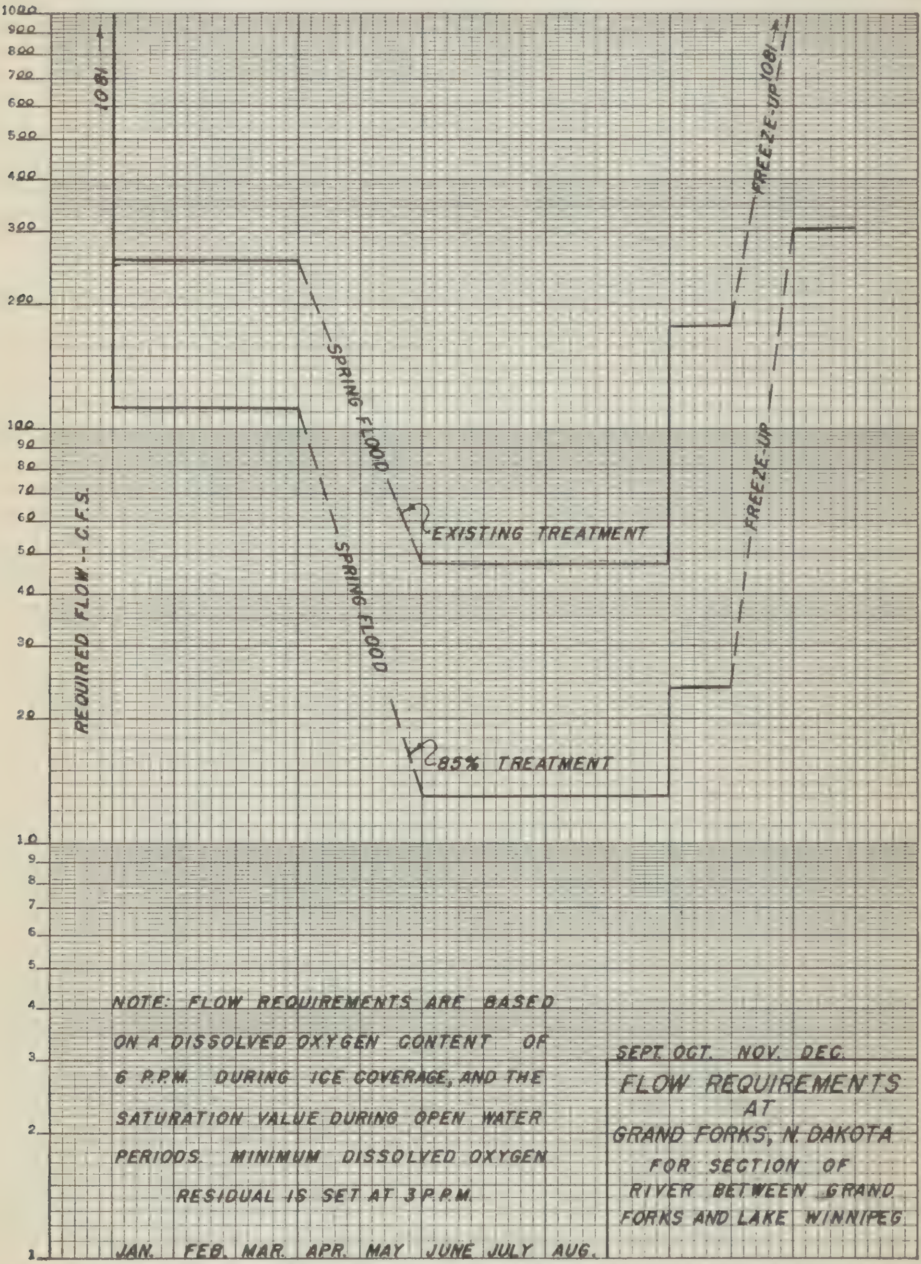
REQUIRED FLOWS — C.F.S.
SPRING FLOOD
85% TREATMENT
EXISTING TREATMENT
FREEZE-UP
NOTE: FLOW REQUIREMENTS ARE BASED ON A DISSOLVED OXYGEN CONTENT OF 6 P.P.M. DURING ICE COVERAGE, AND THE SATURATION VALUE DURING OPEN WATER PERIODS. MINIMUM DISSOLVED OXYGEN RESIDUAL IS SET AT 3 P.P.M.
JAN. FEB. MAR. APR. MAY JUNE JULY AUG.
SEPT. OCT. NOV. DEC.
FLOW REQUIREMENTS
AT
FARGO, NORTH DAKOTA
FOR SECTION OF
RIVER BETWEEN FARGO
AND GRAND FORKS



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REQUIRED FLOW - C.F.S.
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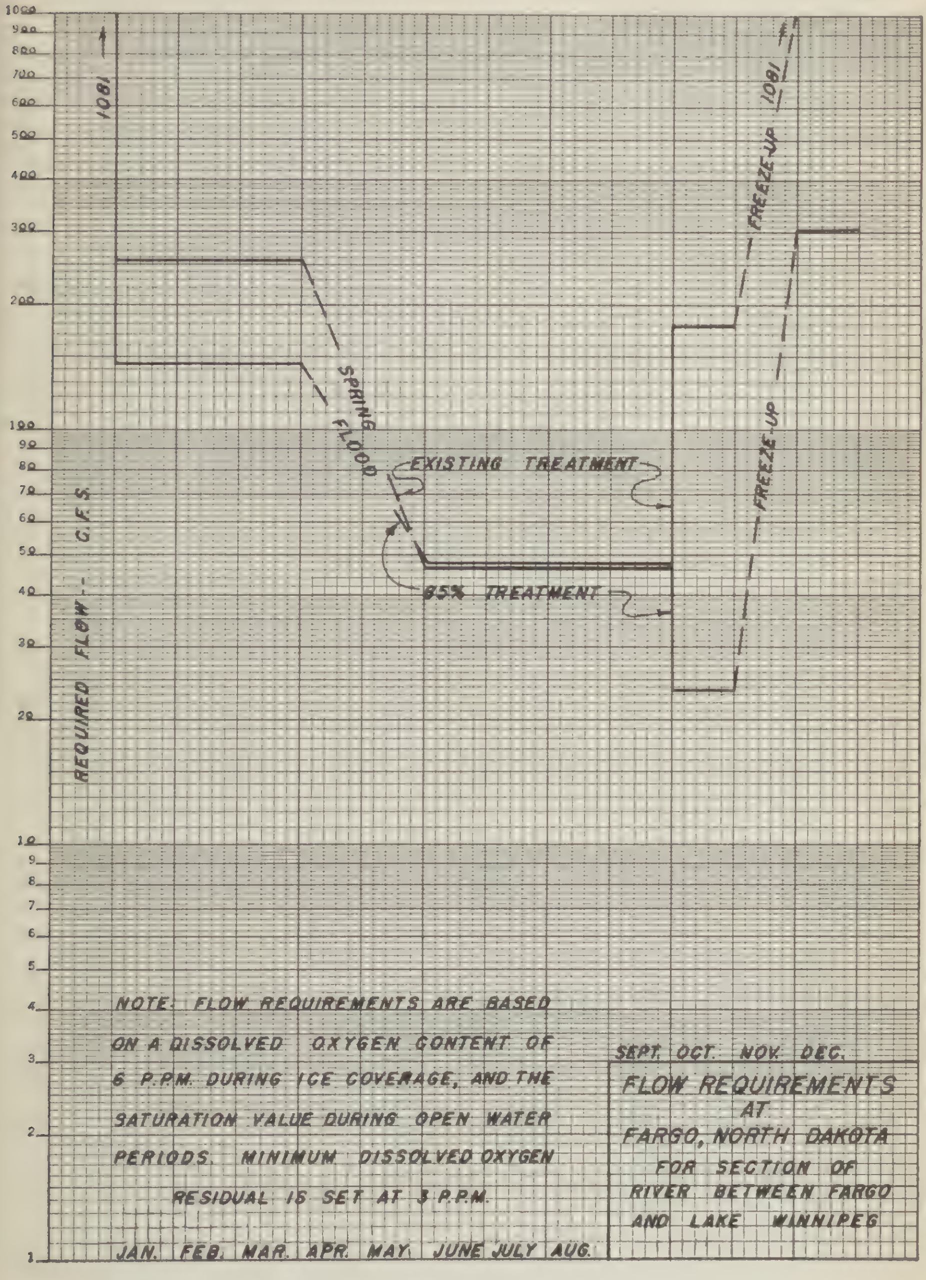
SPRING FLOOD
SPRING FLOOD
EXISTING TREATMENT
85% TREATMENT
FREEZE-UP 1081
FREEZE-UP
NOTE: FLOW REQUIREMENTS ARE BASED ON A DISSOLVED OXYGEN CONTENT OF 6 P.P.M. DURING ICE COVERAGE, AND THE SATURATION VALUE DURING OPEN WATER PERIODS. MINIMUM DISSOLVED OXYGEN RESIDUAL IS SET AT 3 P.P.M.
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
FLOW REQUIREMENTS AT GRAND FORKS, N. DAKOTA FOR SECTION OF RIVER BETWEEN GRAND FORKS AND LAKE WINNIPEG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REQUIRED FLOW - C.F.S.
1081
SPRING FLOOD
EXISTING TREATMENT
85% TREATMENT
FREEZE-UP
FREEZE-UP
1081
NOTE: FLOW REQUIREMENTS ARE BASED ON A DISSOLVED OXYGEN CONTENT OF 6 P.P.M. DURING ICE COVERAGE, AND THE SATURATION VALUE DURING OPEN WATER PERIODS. MINIMUM DISSOLVED OXYGEN RESIDUAL IS SET AT 3 P.P.M.
JAN. FEB. MAR. APR. MAY. JUNE JULY AUG.
SEPT. OCT. NOV. DEC.
FLOW REQUIREMENTS AT FARGO, NORTH DAKOTA FOR SECTION OF RIVER BETWEEN FARGO AND LAKE WINNIPEG

APPENDIX V

Population Data

Table I

TOTAL POPULATION OF THE RED RIVER BASIN BY WATERSHEDS

State Sub-basin	1890	1900	1910	1920	1930
Minnesota—Bois de Sioux	10,917	17,070	16,898	17,155	18,199
Buffalo-Wild Rice	39,000	56,070	60,549	70,594	71,677
Ottertail	26,085	37,056	40,913	45,182	46,614
Red Lake	21,304	39,690	52,882	62,640	58,448
Snake-Roseau	16,631	31,866	36,190	40,497	37,625
Minnesota Total	113,937	181,952	207,430	236,068	232,563
North Dakota—Sheyenne	29,373	57,706	86,279	89,210	88,032
Wild Rice	13,379	19,854	24,711	25,452	24,989
Other	70,453	108,890	116,695	125,786	135,486
North Dakota Total	113,205	186,450	227,685	240,448	248,507
South Dakota Total	950	7,075	7,891	8,688	8,021
Red River Basin Total	228,092	375,277	443,006	485,204	489,091

Table II

RURAL FARM AND NON FARM POPULATION OUTSIDE INCORPORATED PLACES

Red River of the North Drainage Basin

State Sub-basin	1890	1900	1910	1920	1930
Minnesota—Bois de Sioux	9,279	12,977	11,736	12,275	13,011
Buffalo-Wild Rice	33,526	45,098	43,831	50,333	49,424
Ottertail	18,624	23,818	23,005	24,854	24,609
Snake-Roseau	15,110	27,564	29,081	31,324	28,962
Red Lake	15,894	26,737	32,971	40,703	37,071
Minnesota Total	92,433	136,194	140,624	159,489	153,077
North Dakota—Sheyenne	25,365	50,140	66,832	66,708	64,702
Wild Rice	12,922	17,977	19,073	19,551	19,247
Other	50,787	69,182	63,380	60,828	59,177
North Dakota Total	89,074	137,299	149,285	146,887	143,126
South Dakota Total	950	6,869	7,304	7,426	6,854
Red River Basin Total	182,457	280,362	297,213	313,802	303,057

Table III

POPULATION OF INCORPORATED PLACES (Less Than 2,500)

Red River of the North Drainage Basin

State Sub-basin	1890	1900	1910	1920	1930	No. Vill.
Minnesota—Bois de Sioux	1,638	4,093	5,160	4,880	5,188	12
Buffalo-Wild Rice	3,386	7,242	11,878	14,541	14,602	33
Ottertail	2,435	5,456	8,214	9,321	8,941	14
Red Lake	967	3,698	6,105	7,937	7,866	21
Snake-Roseau	1,521	4,302	7,109	9,173	8,663	21
Minnesota Total	9,947	24,791	38,466	45,852	45,260	101
North Dakota—Sheyenne	2,919	5,120	14,841	17,816	16,062	40
Wild Rice	457	1,877	5,638	6,101	5,742	13
Other	10,112	24,913	26,506	23,406	24,266	54
North Dakota Total	13,488	31,910	46,985	47,323	48,070	107
South Dakota Total	.....	206	587	1,262	1,167	6
Red River Basin Total	23,435	56,907	86,038	94,437	94,497	214

Table IV

URBAN POPULATION (Over 2,500)

Red River of the North Drainage Basin

State	Sub-basin	1890	1900	1910	1920	1930	No. Cities
Minnesota—	Bois de Sioux....	.....	.....	.....	.....	.....	..
	Buffalo-Wild Rice	2,088	3,730	4,840	5,720	7,651	1
	Ottertail........	5,026	7,782	9,694	11,007	13,064	2
	Red Lake.......	4,443	9,255	13,806	14,000	13,511	3
	Snake-Roseau....	.....	.....	......	......	......	..
Minnesota Total............		11,557	20,767	28,340	30,727	34,226	6
North Dakota—	Sheyenne....	1,089	2,446	4,606	4,686	5,268	1
	Wild Rice....	.....	.....	......	......	......	..
	Other.......	9,554	14,795	26,809	41,552	52,043	4
North Dakota Total.........		10,643	17,241	31,415	46,238	57,311	5
South Dakota Total.........		.....	.....	......	......	......	..
Red River Basin Total.......		22,200	38,008	59,755	76,965	91,537	11

Stream Pollution Other Than Sewage or Industrial Wastes. Garbage, Trash and Rotten Potatoes Dumped on Red River.

APPENDIX VI

Dilution Water Sources

THE SUITABILITY OF RELATIVELY UNPOLLUTED STREAMS FOR DILUTION PURPOSES

Investigations were made as to the suitability of relatively unpolluted streams under ice coverage for dilution purposes. Three tributaries of the Red River, namely the Wild Rice, Buffalo, and Sheyenne, as well as the Missouri River, were studied in order to formulate some conclusions.

Sheyenne River at Valley City

Above Valley City the only municipal sewage discharged into the Sheyenne River is from Harvey (population 2,200—no treatment—distance approximately 290 miles). Flow in the Sheyenne at Valley City ceased about July 10-15, 1939, and did not resume again until spring breakup. The Faust dam, approximately 12 feet high, located about six miles above Valley City, and the Mill dam, approximately 10 feet high, located in Valley City, provide channel storage. Sampling stations were established in the reservoir a few yards above the Faust dam and approximately one mile above the Mill dam, the latter at a point above sources of pollution from residential areas in the city. The reservoirs froze over about December 25, 1939. The first sample taken at Faust dam on January 27, 1940, showed only 0.2 p.p.m. dissolved oxygen.

About eight weeks after ice coverage, no dissolved oxygen could be detected at either station. On February 16, the gate in Faust dam was opened and the reservoir lowered to such an extent that no further samples could be obtained. A stretch of open water extending about 200 feet below the dam resulted from the flow through the gate. Sampling was continued at the Mill dam station, several miles below Faust dam, but no recovery was perceptible at this station.

From the above, it appears that even in relatively unpolluted streams the B.O.D. from natural sources such as surface runoff, bottom sediment, and decaying vegetation, is sufficient to cause serious oxygen depletion. It is agreed that storage is not great in these channel reservoirs. However, the results may point to the conclusion that, even in relatively large storage reservoirs, aeration upon release is necessary to provide dissolved oxygen for dilution purposes. Detailed data is presented in the table following.

Wild Rice River (Minnesota) (Station J)

The Wild Rice River, because of its low B.O.D. at the mouth, may be considered relatively unpolluted. However, the dissolved oxygen decreased to 9.8 per cent saturation on February 15, 1939, approximately three months after ice formation. This may be due partially to sewage from Twin Valley (population 657—82 miles—no treatment) and Mahnomen (population 989—118 miles—no treatment). An overflow dam at Twin Valley provides aeration. Flows during February 1939 averaged 17 c.f.s. Without aeration

provided either prior to or after its confluence with the Red River, this stream is considered of little value for dilution purposes. With a minimum flow of 7 c.f.s. during February 1940, zero dissolved oxygen was observed approximately six weeks after ice coverage.

Buffalo River (Minnesota) (Station K)

Samples from the Buffalo River during the 1938-39 winter season indicated B.O.D. values over 6 p.p.m. due probably to the discharge of raw sewage from Hawley (population 958—36 miles above station) and Barnesville (population 1,279—45 miles above station.)

The dissolved oxygen in this case dropped to practically zero within two weeks after ice coverage and remained at zero for the following 3½ months. The following year, freeze-up occurred at approximately the first of January and no extensive sampling was carried on thereafter.

Red River above Fargo

The Red River above Fargo illustrates the capacity of a stream to satisfy oxygen demand during ice coverage where aeration is provided. Breckenridge (population 2,264) and Wahpeton (population 3,136) were discharging raw sewage into the Red River during the winter of 1938-1939. (Wahpeton has since installed a treatment plant). Flows averaged approximately 100 c.f.s. during January and February 1939. The dissolved oxygen at Fargo (Station 12) during this time averaged about 10 p.p.m.; one sample showed 6 p.p.m. Undoubtedly, aeration provided by the overflow dams in the stream account for the satisfactory condition. One dam is located in Breckenridge and one in Wahpeton (97 and 96 river miles from Fargo); two 9-foot dams are located 43 miles and 32 miles above Fargo, respectively, and a 3-foot dam is located 5 miles above Fargo. In view of the fact that observations showed a maximum of about 6 p.p.m. dissolved oxygen picked up by an oxygen-deficient water in flowing over these types of dams, the condition at Fargo is probably a result of the progressive effect of each dam. It should be noted, however, that these dams were not constructed primarily for aeration purposes and their efficiency as aerating devices could most likely be greatly improved.

Missouri River at Bismarck

Dissolved oxygen in the Missouri River at Bismarck was determined frequently during the winter of 1938-1939. In North Dakota, the only municipalities discharging sewage into this stream are Washburn (population 800—60 miles) and Williston (population 5,000—300 miles). No treatment is provided at either of these municipalities. A beet suger refinery at Sidney, Montana, probably discharges considerable waste into the Yellowstone River, principal tributary of the Missouri River. There are no dams in the stream to provide aeration during winter months in North Dakota. However, portions of the River remain open during moderately severe

sub-zero weather because of the swift currents. Flows were in excess of 5,000 second feet during the entire winter. The fact that dissolved oxygen decreased to 9.8 p.p.m. during the latter part of the ice coverage period (see following table) indicates that considerable oxygen demand is satisfied in this relatively unpolluted stream and that critical dissolved oxygen conditions may occur if pollution is increased at the same time that flows are markedly below normal. The rich organic bottom deposits occurring in streams in the Red River Valley are not generally present in the Missouri River because of the high stream velocities. A tabulation of dissolved oxygen determinations on the Missouri River is included.

SHEYENNE RIVER AT VALLEY CITY

Date	FAUST DAM*			MILL DAM**		
	Temp.	Dissolved Oxygen	Remarks	Temp.	Dissolved Oxygen	Remarks
1-27-40	2°C.	0.2 p.p.m.	....	....	...	....
2- 3-40	2°C.	0.0	Odor	3°C.	1.4	....
2- 9-40	....	...	....	3°C.	0.6	....
2-17-40	2°C.	0.0	Odor	3°C.	0.0	Odor
3- 1-40	....	...	....	2°C.	0.0	Odor
3-12-40	....	...	....	2°C.	0.0	Odor
4- 1-40	....	...	....	3°C.	0.0	Odor

Freeze-up about December 25, 1939.
The gate in Faust Dam was opened Feb. 16, 1940.
The river opened up about April 5, 1940.

NOTE:
Temperatures above 0°C. observed under ice coverage are believed to result from appreciable infiltration from springs and other ground water sources. Thermometers used were checked to eliminate the possibility of thermometer error.
*Located about six miles above Valley City. Dam about 12 feet high.
**Located just above Valley City about one-fourth mile above residential area. Channel reservoir created by 10-foot dam in Valley City approximately one mile below sampling station.

DISSOLVED OXYGEN—MISSOURI RIVER
At Bismarck, North Dakota

Date	Station	Temp.	pH	Dissolved Oxygen	Remarks
11 -7-38	River*	2°C.	8.2	12.9*	
	Plant‡	2°C.	...	12.8‡	
11-16-38	River*	0°C.	...	12.7*	
	Plant‡	0°C.	...	12.7‡	Ice floating in River
11-22-38	River*	0°C.	...	12.6*	
	Plant‡	0°C.	...	12.6‡	Ice floating in River
11-28-38	Plant	0°C.	8.1	13.1	R. ice covered for about 4-5 days
12 -6-38	Plant	0°C.	8.1	12.9	River ice covered
12-13-38	Plant	0°C.	8.1	12.7	
12-20-38	River	0°C.	8.1	12.8	Hole in ice—13 ½′ water
12-30-38	Plant	0°C.	8.1	12.9	
1-12-39	River*	0°C.	...	11.7	*600′ above R.R. bridge—ice harvesting, 10′ water. Few small open stretches
	Plant	0°C.	8.1	11.7	
1-16-39	River*	0°C.	8.0	11.7	
	Plant‡	0°C.	...	11.7	*600′ above R.R. bridge—20″ ice 6′ of water
2-11-39	Plant	0°C.	8.0	10.8	
2-18-39	Plant	0°C.	8.0	10.3	
2-25-39	Plant	0°C.	7.9	9.8	
3- 6-39	Plant	0°C.	8.0	10.9	
3-17-39	Plant	0°C.	8.0	10.8	
4- 6-39	Plant	3.5°C.	7.9	11.2	
4-22-39	River	10°C.	...	11.3	
5 -5-39	River	17°C.	...	8.4	
5-31-39	Plant	18.5°C.	...	7.65	
6-15-39	River	17°C.	...	8.13	
6-15-39	Plant	17°C.	...	8.18	

Note: *Sample taken directly from river.
‡Sample taken at inlet well, Bismarck water treatment plant.

SANITARY SURVEY OF THE RED RIVER OF THE NORTH

REPORT OF JOINT INVESTIGATION

by the

North Dakota State Department of Health

and the

Minnesota State Department of Health

February, 1938

SANITARY SURVEY OF THE RED RIVER OF THE NORTH FROM GRAND FORKS TO PEMBINA, NORTH DAKOTA

February, 1938

This survey was made by the Minnesota and the North Dakota departments of health to follow up a previous investigation which extended from 1931 through 1933, and covered the river from Breckenridge, Minnesota to the International boundary.*

Since the 1931-1933 survey, there have been some changes in the factors which affect the pollution of the Red River. The cities of Fargo and Grand Forks in North Dakota, and the cities of Moorhead and Fergus Falls in Minnesota, have installed sewage treatment plants for the treatment of their domestic sewage. The packing plant at West Fargo has provided treatment for its wastes and the beet sugar factory at East Grand Forks passes its waste water through lagoons before discharging it to the river.

A new dam has been erected in the Ottertail River above Breckenridge, Minnesota and Wahpeton, North Dakota to assure these towns of a more dependable source of water supply, and a series of reservoirs has been installed on the Ottertail River basin which should provide a more constant flow of water to the Red River.

The following table shows the present status of treatment of municipal and industrial waste on the Red River:

*Pollution of the Red River of the North. Report of Joint Investigation by the Minnesota Department of Health and the North Dakota State Board of Health in collaboration with the Division of Game and Fish, Minnesota Department of Conservation, 1931, 1932, and 1933.

Status of Municipal and Industrial Waste Treatment on the Red River

Municipality (population 1930) or industry (population equivalent)	Treatment	Year Completed
Wahpeton, N.D. 3,900	None	
Breckenridge, Minn. 2,264	None	
Fargo, N.D. 28,619	Bar screen, detrition, primary clarifier, trickling filter, primary and secondary sludge digestion, sludge beds	1935
Moorhead, Minn. 7,651	Bar screen, primary clarifier, trickling filter, final settling, separate sludge digestion, sludge beds	1935
Armour Packing Plant, West Fargo, N.D. 46,400*	Fine screens, primary settling, primary filters, mechanical clarifiers, primary and secondary trickling filters, primary and secondary mechanical clarifiers, pre- and post-chlorination	1938
Grand Forks, N.D. 17,112	Bar screen, grit chamber, aeration, chemical precipitation, primary clarifier, primary and secondary sludge digestion, sludge beds	1937
East Grand Forks, Minn. 2,922	None	
American Crystal Sugar Co., East Grand Forks, Minn. 142,000**	Settling Lagoons	1934
Northern Packing Co., Grand Forks, N.D. 7,200***	Settling tanks	Prior to 1931
Grafton, N.D. 3,136	Bar screen, grit chamber, primary clarifier, trickling filter, primary and secondary sludge digestion, sludge beds	

*1933 Report. Population equivalent based on average kill of 2,000 animals per day and 27.8 per animal, from Bulletin 171, United States Public Health Service. Figure shown allows for 16½ per cent reduction of biochemical oxygen demand by screens.

**1933 Report. Population based on oxygen demand data.

***Estimate; oxygen demand data lacking.

PRESENT SURVEY

Because numerous complaints had been received from farmers in the Red River basin north of Grand Forks, the present survey was confined to that section of the river between Grand Forks and the Canadian border. Meetings were held at Oslo, Drayton, and Joliette, for riparians and residents along both sides of the Red River, and eighty-nine farmers and residents who owned or rented more than 6,800 acres along the river were interviewed. The following is a summary of the principal facts obtained:

1. Eighteen persons stated that they used either water or ice from the river for drinking and cooking purposes. Of this number, three farmers said that they boiled the water before using it for drinking. Ten farmers said that they depended upon melted river ice for drinking purposes.
2. Altogether forty persons stated that they used melted ice from the river for cooking.
3. River water or melted ice or both were used for washing and laundry purposes by seventy persons.
4. According to the statement of ten farmers, they used the river water for irrigating small gardens.
5. Seventy-eight persons complained of bad odors and objectionable conditions in the river during the season of open water.
6. Seventy-one farmers stated that they water from the river, a total of 4,296 head of stock, mostly cattle.
7. Many farmers who were dependent on river water for stock stated that during winter months their cattle drank very little water; that dairy cattle, due to heavy feeding, would bloat and become very sick, some of them dying.

The points chosen for sampling the river were the same as those used in the previous investigation, and were located as follows:

Station	Miles below Station 11	Description
11	0	Red River at Lincoln Park as it enters Grand Forks.
12	2	Red River at dam in Riverside Park below sewer outlets of East Grand Forks and the beet sugar factory.
14		Red Lake River at water intake.
13	28	Red River at bridge at Oslo, Minn.
G	23	Red river at site of old pontoon bridge east of Grafton, N. Dak.
D	93	Red River at bridge at Drayton, N. Dak.
P	143	Red River at bridge between Pembina, N. Dak., and St. Vincent, Minn.

Sources of Pollution: In the section of the stream investigated, the principal sources of pollution were at Grand Forks, N. Dak. and East Grand Forks, Minn. At East Grand Forks, pollution consists of untreated sewage from the municipal sewer system and the waste from the beet sugar factory.

Nothing has been done regarding the treatment of sewage at East Grand Forks. The beet sugar factory constructed lagoons in 1934 so as to pond their waste water, to allow settling of the suspended material and to permit the re-use of some of the water. This form of treatment has been of limited value, however, for the oxygen demand of the waste after it has settled is still high, and the strength of the effluent has been observed to increase as the season progressed. This increase in strength refers particularly to the five-day biochemical oxygen demand and has been discussed in a brief report made by the Minnesota Department of Health in 1935*. Re-use or re-circulation of a part of the waste for utilization in the plant, physico-chemical changes in the beets brought about by freezing, and the effect of sludge accumulations in the lagoon are factors which contribute to an increase in the strength of wastes as the operating season advances. The plant operates from 85 to 90 days each year, beginning in mid-September.

At Grand Forks, polluting materials come from the untreated waste of the Northern Packing Company, from the State Flour Mill, and from the sewage treatment plant which, at the time of the investigation, was utilizing only primary treatment. All of the wastes from Grand Forks enter the stream below the Riverside dam and all from East Grand Forks, above the dam. None of the towns on the Red River north of Grand Forks have a sewerage system. In this area, the hospital at Drayton is, as far as is known, the only establishment that discharges sewage directly to the river. The village of Grafton, which is situated ten miles west of the Red River, discharges treated sewage into the Park River which, in turn, discharges into the Red River, but a sample of the Park River water showed that this stream, at the time of the investigation, was not a material factor in the pollution of the Red River. Tributaries on the Minnesota side of the river which were investigated for possible pollution were found to be frozen to the bottom.

The principal changes as far as pollution is concerned since the previous survey has been the installation of treatment for the sewage of the City of Grand Forks and the discharge of its waste below instead of above the dam. On the Minnesota side, the ponding of the beet sugar factory waste before it is discharged to the river has been the only alteration.

Analytical Results: The analytical determinations included dissolved oxygen, five-day biochemical oxygen demand, coli-aerogenes, solids, plankton, and the examination of bottom sediment. One set of samples only was collected for solids, plankton, and bottom sediment, but for the other determinations three or more samples were collected at each station.

Table 1 shows a tabulation of the five-day biochemical oxygen demand, dissolved oxygen and coli-aerogenes results, and Table 2

*Report on the Waste Treatment Plant of the American Beet Sugar Company. East Grand Forks, Minnesota. October and November, 1934.

gives the maximum, minimum and average results for five-day biochemical oxygen demand and coli-aerogenes. The coli-aerogenes results are expressed as the most probable number per 100 cubic centimeters, and were calculated on the basis of using three tubes in each dilution.

Table 3 is a summary of results obtained in the determination of hardness, pH and solids.

Table 4 is the tabulation of the organisms which occur in the bottom sediment of the river, expressed as numbers of organisms per square yard of bottom area. Table 5 is a summary and condensation of the preceding table with respect to the occurrence of pollutional index organisms. The number and kinds of plankton organisms occurring at each station are presented in Tables 6 and 7. The plankton results are expressed in terms of numbers of organisms per liter in the case of nannoplankton, Table 6, and as numbers per 100 liters in the case of the net plankton, Table 7.

The river was completely ice-locked at the time of the investigation except for a small stretch below the Riverside Dam at Grand Forks. The dissolved oxygen test showed no oxygen at any of the stations except Station 14 on the Red Lake River. At all of the stations except 14, the odor of hydrogen sulphide was noticeable. At stations north of Grand Forks, this odor became increasingly pronounced until at Pembina the water was extremely foul.

Table 1 and Table 2 show the five-day biochemical oxygen demand increasing as the stream flows north. Since, as far as is known, no heavy pollution enters the stream north of Grand Forks, the rise in biochemical oxygen demand in downstream samples may possibly be attributed to the flow of the water over sludge beds which are decomposing under anaerobic conditions. It is possible that the sludge, in undergoing decomposition, liberates soluble organic matter or colloidal material which is picked up by the stream. Furthermore, the character of the sludge may change so that it floats or can be carried along even by a very sluggish stream. Still another explanation is that under anaerobic conditions a "delayed demand" is created which is satisfied when oxygen is again available. One or all of these may be possible factors in accounting for the rise in five-day biochemical oxygen demand as the stream flows northward under septic conditions and over sludge deposits. Table 3 shows the results obtained on the determination of solids on one set of samples. A significant rise in suspended and volatile matter is indicated at Stations G, D, and P. This corresponds closely with the rise in five-day biochemical oxygen demand.

The wide variation between maximum and minimum results at Station 12 is attributed to the difference in sampling depths. This station was located at the pool back of the Riverside Dam. Three of the samples were taken near the bottom and show the high biochemical oxygen demand of the water just above the sludge deposits. This condition is also reflected in the determina-

tions of solids from this point, which showed the highest total, suspended, and volatile matter of all stations. The fourth sample at Station 12 was taken near the surface and had a biochemical oxygen demand of only fifteen parts per million as compared with 200 or greater at the bottom. The surface sample represented more nearly the water which was going over the dam.

Station 14, on the Red Lake River, had the lowest five-day biochemical oxygen demand results and indicated that the oxygen demand established by pollution of this stream at points above had been largely satisfied and that it was not an important factor in the pollution of the Red River, at least during the time of this investigation. This station also has a small amount of dissolved oxygen.

Station 11, being above all immediate sources of pollution, was least septic of the stations on the Red River but proved to be slightly more polluted than Station 14 on the Red Lake River.

Coli-Aerogenes. Results from all stations on the Red River from the Riverside Dam to Pembina showed that the number of coli-aerogenes organisms was of about the same magnitude. The counts ranged from a minimum of 7,500 to a maximum of 46,000 per 100 cubic centimeters. The station at Grafton showed consistently slightly lower results than Stations 13, D or P. This might possibly be due to the fact that this station is not in the immediate vicinity of a community. Station 14 on the Red Lake River proved also to be the least polluted with respect to coli-aerogenes. It has a maximum count of 75 coli-aerogenes organisms per 100 cubic centimeters.

Comparison of Results with those of Former Survey: In comparing the five-day biochemical oxygen demand results obtained in this survey with those of the earlier investigation, it becomes evident that the results obtained this year are as high as and in some cases higher than the maximum demands observed previously. The maximum biochemical oxygen demand recorded for the earlier survey occurred in December, 1933, during the early period of ice coverage and at a time when beet sugar wastes were discharged into the stream. Samples collected this winter were also taken during the period of ice coverage but the collections were made later, approximately a month after the close of the operating season of the American Crystal Sugar Company.

This winter, as shown in Table 8, the five-day biochemical oxygen was much higher at Stations 11 and 12 and at Pembina than formerly. At Grafton and at Drayton, results were similar to those obtained in the prior investigation, while results from Stations 13 and 14 were slightly lower. As intimated earlier, the extremely high demands which occurred at Station 12 this season may be attributed to the depth of sampling. The highest demand occurred near the bottom and pointed to the presence of an extensive de-

posit of sludge, rich in organic matter. In part, at least, this sludge was derived from the deposition of beet sugar wastes behind the dam.

Dissolved oxygen was depleted at all points in the Red River and offensive odors prevailed. This condition was very similar to that observed while the stream was under ice coverage during the winter of 1932-33.

It is difficult to compare the bacteriological results in this case because the results were reported according to Phelps' index in the earlier investigations and according to the most probable number in this survey. On the basis of a very general consideration, however, it is permissible to make the observation that in contrast to the very substantial increase in the five-day biochemical oxygen demand that occurred at certain stations there was no proportionate increase in the number of coli-aerogenes organisms over that observed earlier.

Station 14, located on the Red Lake River, showed some improvement of conditions as compared to results obtained in 1932 and 1933. Formerly, fairly high five-day biochemical oxygen demands and high bacteriological counts occurred at this station at times, but this winter the demand was reasonably low and the bacteria were few, although the low dissolved oxygen indicated pollution. The improvement noted at this station may be attributed to the construction of a dam, which prevents backflow of contaminated water from the Red River. Oxidation of organic substances from some upstream sources and the inability of the stream to provide re-aeration under ice coverage accounts for the low dissolved oxygen at this point.

Biological Results. Samples of bottom sediment were taken at each station and the organisms removed and counted in accordance with the procedure set forth in the Eighth Edition of Standard Methods of Water Analysis.*

Because the bottom-dwelling organisms have a much reduced metabolism in winter and respond, therefore, more slowly to changes in the environment, there is also a lag in their response to an increase in pollution. It is also true that in winter, when clean-water forms are killed by rather extended periods of oxygen depletion, their bodies may, as a result of prevalent low temperatures, remain in the sediment for long periods before they disintegrate. It is, therefore, necessary to interpret winter data with some care especially where summer and winter conditions may be widely variant. This lag in the response of the biological index of pollution is, in a sense, a disadvantage, but it may also be useful inasmuch as it is evidence of the past characteristics of the stream. If, for example, under winter conditions, the dissolved oxygen is entirely depleted and the biochemical oxygen demand is high, and collections of bottom sediment are made early enough to retain recogniz-

*Standard Methods for the Examination of Water and Sewage, Eighth Edition, American Public Health Association, 1936.

able remnants of clean-water forms, very definite evidence is offered that conditions have been better. It may be assumed from the evidence of these clean-water forms that during periods of open water the stream was relatively unpolluted at that point and that the zone of pollution had advanced downstream under ice coverage as indicated by the other determinations. Conversely, collections containing no clean-water forms indicate that serious pollution exists summer and winter or that the collections of samples took place after the more sensitive forms disappeared through decomposition. In extreme cases even the hardy pollutional types of organisms may be killed off during the later period of ice coverage.

If these facts are kept in mind, the interpretation of the results obtained during this survey is simplified. In this case, there was a complete oxygen reduction in the Red River proper, and the presence of hydrogen sulphide was readily detected. This combination is toxic to most forms of life. The presence of partially decayed mayfly nymphs and gaping, blackened mollusk shells with muscle fragments still adhering to the valves, indicated that clean-water forms were disappearing. A number of clean-water forms—which did not yet show any signs of disintegration—occurred in certain downstream samples. These organisms may have been more resistant to decay or to the increasing oxygen depletion than the soft-bodied mayflies and mollusks. The final disintegration and disappearance of these forms would have been only a matter of time, however, under the conditions which prevailed. In the pool above the dam at Grand Forks, where oxygen depletion probably occurred first, even hardy pollutional types were found as disintegrated fragments.

Because remnants of the clean-water forms which occur in summer still remained at certain points, the full effect of winter conditions was not registered on the bottom fauna at the time of this investigation. The data obtained reflected, therefore, late summer and early fall conditions to a large extent. On this basis, it is evident that serious pollution extends only as far as Station 13 at Oslo in summer during periods of open water. Clean-water forms were missing or were few in number at and above Oslo, and pollutional types predominated. North of Station 13, conditions were improved as was evidenced by increasing numbers of clean-water forms and facultative pollutional types. (See Table 5.)

Pollutional forms were predominant in the sediment samples taken at Station 14 although the supernatant water had a very low five-day biochemical oxygen demand and thus showed no evidence of pollution other than low dissolved oxygen. The construction of a dam across the Red Lake River a short distance below Station 14 has facilitated the deposition of rich organic sediment. This sedimentation has shifted purification from the supernatant water to the bottom material, and thus the deposit reflects some of the artificial or natural upstream pollution of the river. The bottom

organisms have responded to the characteristics of this environment and, in this case, indicate pollution although it is not evident in the water flowing above it.

Plankton organisms unlike the bottom forms respond rather quickly to changes in the environment even in winter, and may vary rapidly with the supernatant water. At the time of this survey, plankton were relatively scarce at most points in the Red River. The nannoplankton, which in the winter of 1933 ranged from one million to twelve and one-half million organisms per liter, reached a maximum of only 67,000 per liter this winter. This maximum occurred at Station 11 above the sources of pollution at Grand Forks and East Grand Forks; all other samples contained lower concentrations of nannoplankton.

The net plankton representing larger, less abundant forms was collected by straining 100 liters through a standard silk net. Appreciable numbers of net plankton forms occurred only at Station 11 and consisted almost entirely of rotifers and immature copepods. Whereas formerly, there had been an increase in rotifers between Station 11 and Station 12, there was now a distinct reduction in numbers. At Station 11 there were 150 rotifers per liter and these were reduced to two per liter at Station 12. Although rotifers feed on bacteria and normally occur in large numbers where pollution exists, they do succumb to extreme conditions. Their sudden disappearance in so short a distance may be attributed to definite increase in pollution. Below Station 12 neither rotifers nor crustacea were taken in the plankton collections. With respect to pollution, increasingly unfavorable conditions are therefore indicated by the character and concentrations of net plankton and nannoplankton in the Red River below Station 11.

The following tables show the quantity of water flowing in the Red River during the time of the survey and during the winter of 1937-38, and comparative flows in 1932-34:

Discharge Records*

Discharge in cubic feet per second of the Red River of the North at Grand Forks, North Dakota. Measurements taken downstream from the junction of the Red Lake River and the Red River below Riverside Park Dam.

Date	Flow in Cu.Ft./Sec.
Feb. 1	66
Feb. 2	77
Feb. 3	89
Feb. 4	89
Feb. 5	81
Feb. 6	73
Feb. 7	66
Feb. 8	63
Feb. 9	63
Feb. 10	77
Feb. 11	91
Feb. 12	91
Feb. 13	94
Feb. 14	89
Feb. 15	82
Mean Velocity	0.30 feet per second

Discharge Cu.Ft./Sec. 1937-1938

Month	Mean	Maximum	Minimum	Mean Velocity Ft./Sec.
October	316	484	166	0.85
November	214	336	94	0.75
December	55.9	95	30	0.42
January	61.3	91	36	0.34
February	82.5	113	63	0.30

Discharge Cu.Ft./Sec. 1933-1934

Month	Mean	Maximum	Minimum
October	31.7	60	21
November	79.0	135	50
December	52.5	61	42
January	39.0	56	18
February	40.7	64	24

Discharge Cu.Ft./Sec. 1932-1933

Month	Mean	Maximum	Minimum
October	36.0	100	13
November	82.7	114	64
December	57.4	81	33
January	38.6	48	31
February	33.6	76	—

*From records of the United States Geological Survey, Office of District Engineer, St. Paul, Minnesota.

SUMMARY AND CONCLUSION

Information collected during this investigation agrees in general with that obtained in the former survey at the same season and on this portion of the river. It is apparent, however, that from the standpoint of oxygen resources the stream showed more marked evidence of pollution this winter than formerly. There was no trace of dissolved oxygen, the five-day biochemical oxygen demand was considerably higher, plankton organisms were seriously reduced and offensive odors were more general. Therefore, in spite of slightly higher stream flow and partial treatment of certain types of wastes, conditions seem to have been aggravated this winter.

To minimize these objectionable conditions in the stream, it will be necessary to reduce further the oxygen requirements of the wastes now discharged into the river. This will involve provisions for effective treatment of sewage from East Grand Forks and will necessitate additional treatment of wastes from the American Crystal Sugar Company. Further reduction in the strength of the sewage from Grand Forks is needed and treatment should be provided for the wastes from the flour mill and the packing plant.

This investigation confirmed the conclusions and requirements of the previous survey which were as follows:

"The Minnesota State Board of Health and the North Dakota State Department of Health are of the opinion, based on the findings of this investigation, that in order to improve the existing polluted condition of the Red River and to promote the best interests of those concerned, it will be necessary to provide treatment for the sewage and industrial wastes from all of the municipalities from Breckenridge to Grand Forks and East Grand Forks, inclusive, and for all of the major industrial wastes which are discharged separately into the section of the river under consideration."

It can also be logically concluded that this study has shown the desirability of carrying out a more extensive research investigation on the Red River of the North in order to determine the full effects of ice coverage. The period covered in such an investigation should extend from a time before freeze-up in the fall to several months after break-up in the spring. Sampling should include all flowing tributaries.

Tabulation of Dissolved Oxygen, Five-Day Biochemical Oxygen Demand, and Coli-Aerogenes Results

Station	Determination	2/2/38	2/3/38	2/4/38	2/7/38	2/8/38	2/9/38
11	5-day B.O.D.	....	6.4	3.9	.....	12	4.6
	D.O.	....	0.0	0.0	.....	0.0	......
	Coli-Aerog.	....	230	150	.....	230	91
12	5-day B.O.D.	....	150	15	.....	276+	235
	D.O.	....	0.0	0.0	.....	0.0	......
	Coli-Aerog.	....	9,300	24,000	.....	4,300	270
14	5-day B.O.D.	....	2.7	2.9	.....	2.2	2.7
	D.O.	....	1.2	0.7	.....	0.15	......
	Coli-Aerog.	....	36	73	.....	75	30
13	5-day B.O.D.	12	....	13	.....	10	8
	D.O.	0.0	....	0.0	.....	0.0	......
	Coli-Aerog.	....	....	46,000	9,300	....	21,000
G	5-day B.O.D.	15	....	17	.....	18	16
	D.O.	0.0	....	0.0	.....	0.0	......
	Coli-Aerog.	....	....	9,300	7,500	....	9,300
D	5-day B.O.D.	26	....	33	.....	16	18
	D.O.	0.0	....	0.0	.....	0.0	......
	Coli-Aerog.	....	....	15,000	24,000	....	24,000
P	5-day B.O.D.	93	....	98	.....	82	80
	D.O.	0.0	....	0.0	.....	0.0	......
	Coli-Aerog.	....	....	9,300	24,000	....	15,000

RED RIVER OF THE NORTH SURVEY
February, 1938
Table 1

5-Day B.O.D. and Coli-Aerogenes Numbers
Results Expressed as Maximum, Minimum, and Average
(A) B.O.D.

Station	Maximum	Minimum	Average
11	12	3.9	6.7
12	276+	15	169
14	2.9	2.2	2.6
13	13	8	11
G	18	15	17
D	33	16	23
P	98	80	88

(B) Coli-Aerogenes

Station	Maximum	Minimum	Average
11	230	91	164
12	24,000	270	4,020
14	75	30	49
13	46,000	9,300	20,800
G	9,300	7,500	8,650
D	24,000	15,000	20,500
P	24,000	9,300	15,000

RED RIVER OF THE NORTH SURVEY
February, 1938
Table 2

TABULATION OF CHEMICAL ANALYSIS
Hardness, Alkalinity and Solids as Parts Per Million
February 2 and 3, 1938

Determination	Sta. 14	Sta. 11	Sta. 12	Sta. 13	Sta. G	Sta. D	Sta. P
Total Hardness................	790	570	1,000	740	720	660	770
Alkalinity.....................	470	560	820	470	410	440	490
pH........................	7.5	7.6	7.1	7.4	7.4	7.4	7.4
Total Solids..................	1,100	760	1,500	1,100	1,100	1,000	1,200
Total Suspended Solids.........	2.3	9	54	7.5	6	11	40
Total Volatile Matter...........	300	250	520	310	250	270	330
Total Suspended Volatile Matter.	2.3	5.5	54	6	3.5	10	30

RED RIVER OF THE NORTH SURVEY
Table 3

BOTTOM FAUNA

Organisms per Square Yard

Organisms	Station No. 14		Station No. 11		Station No. 12		Station No. 13		Station G		Station D		Station P	
	*West	East	South	North	West	East	South	North	West	East	West	East	West	East
Limnodrilus	259	1,187	940	564	12	...	165	329	94	306	12	82	47	188
Tubifex	...	...	47	...	...	...	...	...	...	...	...	...	...	...
Naididae	24	235	...	...	...	...	670	94	12	12	...	...	...	...
Erpobdella punctata	...	12	...	12	...	...	35	...	24	59	...	12	...	24
Glossiphonia complanata	...	...	...	...	...	...	...	...	24	...	...	...	...	...
Nematodes	...	...	...	...	12	...	...	...	...	...	...	...	...	...
Ephoron	...	12	...	...	...	...	...	...	...	...	...	...	...	...
Polycentropidae	...	...	...	...	...	...	...	12	240	71	...	1,340	82	...
Chaoborus punctipennis	...	...	47	...	...	...	24	12	...	...	...	...	...	...
Chironomus sp. No. 1	...	...	...	...	...	...	...	82	12	24	176	188	...	...
Chironomus decorus	...	...	24	881	†	12	...	...	12	...	...	...	...	...
Palpomyia	12	...	24	...	...	...	71	12	35	35	...	141	12	200
Pentaneura carnea	...	...	...	200	...	...	...	59	240	...	...	2,515	153	24
Pentaneura decolorata	...	...	...	...	...	...	71	††	...	...	...	...	...	...
Procladius culiciformis	71	223	176	341	...	12	...	...	12	...	...	...	...	47
Tanypus species	...	...	...	...	...	...	...	...	...	24	...	...	...	...
Amnicola	12	12	...	...	...	...	...	...	...	...	...	141	...	...
Sphaerium	59	12	35	24	...	...	118	82	306	‡710	‡‡388	35	...	...
Ferrissia	...	...	...	...	...	...	...	...	...	12	...	...	...	...
Valvata	...	...	...	...	...	...	...	...	...	...	...	12	...	...
Hyallela knickerbockeri	12	...	...	...	...	...	...	...	24	...	...	82	...	...

†Jaws and heads of decomposed C. decorus present.
††Decayed remains of mayfly mymphs present.
‡Only one-third of total number of shells taken—remaining fingernail clams dead.
‡‡Very small, young specimens.
*Refers to side of river bank.

RED RIVER OF THE NORTH SURVEY
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Table 4

BOTTOM FAUNA

Summary and Classification as Pollutional Index Organisms

Station	Pollutional Forms		Facultative Pollutional Forms		Clean-Water Forms		Total No. Per Sq. Yd.	No. of Species
	Average No. Per Sq. Yd.	Per Cent	Average No. Per Sq. Yd.	Per Cent	Average No. Per Sq. Yd.	Per Cent		
14	864	80.7	194	18.2	12	1.1	1,071	9
11	1,234	74.5	411	24.8	12	0.7	1,657	9
12	18	75	6	25	0	0.0	24	4
13	646	70.4	223	24.4	47	5.2	918	10
G	283	24.7	670	58.7	190	16.6	1,144	9
D	94	3.7	1,727	67.4	740	28.9	2,562	10
P	153	39.4	88	22.7	147	37.9	388	6

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Table 5

NANNOPLANKTON

Organism	ORGANISMS PER LITER						
	Sta. 14	Sta. 11	*Sta. 12	Sta. 13	Sta. G	Sta. D	Sta. P
ALGAE							
Myxophyceae							
Oscillatoria sp.	75	Present	...	.....	.....	.....	......
Oscillatoria geminata	92,800	2,880	...	.....	.....	.....	......
	92,875	2,880	...	.....	.....	.....	......
Bacillarieae							
Cocconeis placentula	......	.....	...	Present	.....	.....	......
Cyclotella	38,800	58,300	...	29,500	2,880	2,160	47,500
Diatoma vulgare	Present	Present	...	.....	.....	.....	Present
Gyrosigma	......	50	...	400	Present	.....	......
Homoeocladia sigmoidea	......	.....	...	1,300	125	.....	......
Lysigonium	......	1,350	...	.....	200	150	......
Navicula	75	50	...	150	.....	.....	......
Synedra ulna	525	75	...	1,950	250	75	175
	39,400	59,825	...	33,300	3,455	2,385	47,675
Chlorophyceae							
Ankistrodesmus	......	.....	...	.....	Present	.....	......
Coelastrum microporum	......	.....	...	Present	.....	.....	......
Crucigenia quadrata	......	Present	...	.....	.....	.....	......
Gloeocystis	......	Present	...	.....	.....	.....	......
Scenedesmus quadricauda	......	.....	...	Present	.....	.....	......
PROTOZOA							
Mastigophora							
Trachelomonas volvocina	1,440	2,880	...	.....	.....	2,160	......
Infusoria							
Ciliate protozoa	1,300	1,600	...	1,750	475	200	150
MISCELLANEOUS							
Rotifer eggs	Present	.....	...	.....	.....	.....	......
	2,740	4,480	...	1,750	475	2,360	150
Total No. of organisms Per Liter	135,015	67,185	...	35,050	3,930	4,745	47,825

*Too much sediment—no count could be made.

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Table 6

NET PLANKTON

Organism	ORGANISMS PER 100 LITERS						
	*Sta. 14	Sta. 11	Sta. 12	Sta. 13	*Sta. G	*Sta. D	Sta. P
ALGAE							
Myxophyceae							
Oscillatoria	....	.....	75	120	...	...	.....
Bacillarieae							
Diatoma vulgare	....	.....	...	...	...	...	150
Tabellaria fenestrata	....	.....	...	...	...	...	1,425
	....	.....	75	120	...	...	1,575
PROTOZOA							
Infusoria							
Ciliate protozoa	....	1,600	...	60	...	...	.....
Vorticella	....	200	...	...	...	...	.....
	....	1,800	...	60	...	...	.....
ROTIFERA							
Brachionus capsuliflorus	....	2,100	75	...	...	...	.....
Keratella cochlearis	....	8,900	...	...	...	...	.....
Keratella aculeata	....	1,600	...	...	...	...	.....
Polyarthra trigla	....	1,700	...	...	...	...	.....
Soft-bodied rotifers	....	100	75	...	...	...	.....
Synchaeta	....	400	75	...	...	...	.....
	....	14,800	225	...	...	...	.....
CRUSTACEA							
Nauplii	....	1,100	...	...	...	...	.....
	....	1,100	...	...	...	...	.....
MISCELLANEOUS							
Rotifer eggs	....	11,700	...	...	...	...	.....
	....	11,700	...	...	...	...	.....
Total No. of organisms per 100 liters	....	29,400	300	180	...	...	1,575

*No organisms.

RED RIVER OF THE NORTH SURVEY
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Table 7

Comparison of Oxygen Resources and Bacterial Concentrations
December 1933 and February 1938*

Station	Dissolved Oxygen		5-day B.O.D.		**Coli-Aerogenes	
					Phelps' I	M.P.N.
	Dec. 1933	Feb. 1938	Dec. 1933	Feb. 1938	Dec. 1933	Feb. 1938
14	10.0	0.15	4.7	2.9	1,000	75
11	18.1	0.0	5.5	12	10	230
12	1.0	0.0	78	276+	100,000	24,000
13	0.0	0.0	23+	13	1,000	46,000
G	0.0	0.0	21	18	10,000	9,300
D	0.0	0.0	32	33	1,000	24,000
P	0.6	0.0	9	98	10,000	24,000

*Maximum B.O.D. and bacterial count, and minimum D.O.
**Number of organisms of coli-aerogenes group per 100 ml. at 37°C.

Phelps' I—Coli-aerogenes recorded according to Phelp's Index.
M.P.N.—Coli-aerogenes recorded as most probable number.
B.O.D.—Biochemical oxygen demand, incubated sample, 5 days at 20°C. expressed in parts per million.
D.O.—Dissolved oxygen in parts per million.

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Table 8